Financial & Health Costs of Pesticide Use in Growing Conventional and Genetically Modified Potatoes in Prince Edward Island[1]

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Selected Paper for Presentation at the Annual Meeting of the Canadian Agricultural Economics Society, Halifax, June 2004

[1] Funding for this project was provided from Genome Prairie, Genome Canada and the Alberta Agriculture Research Institute. We thank Cindy Jardine and Jim Unterschultz for very helpful comments and advice.

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ABSTRACT

The majority of potato farming in Canada occurs in tightly clustered geographic locations and requires substantial chemical inputs. The possibility of pesticide drift, pesticide residues on food and the effect of pesticides on the environment, leads to interest in quantifying the different effects that pesticides may have on human health and the environment. This study focuses on the potential use of genetically modified potatoes, the associated issue of pesticide residues in the air, and the potential impact of this on the health of farmers, their families, and others in the context of Prince Edward Island.

Reductions in costs of potato farming and reduced health costs that may be associated with lower pesticide applications in growing genetically engineered potatoes (NewLeaf, NewLeaf Plus and NewLeaf Pro potatoes, each genetically modified for particular traits), relative to conventional potato growing practices in Prince Edward Island are identified and quantified. It is concluded that the financial benefits from the use of fewer inputs with the modified potatoes are significant while the health benefits associated with reduced exposure to pesticides are relatively small.

INTRODUCTION

Prince Edward Island (PEI) constitutes a very small area on the east coast of Canada, approximately 560,000 hectares in size, which produces almost one third of the potato crop in Canada. Potatoes are PEI's primary agricultural cash crop, contributing one third of total cash farm receipts of the province. Potatoes are the fourth largest food crop in the world, popular because of their nutritional value and as a long established staple food for many people. However, potato farming requires good crop yields in succession.

A number of pests and viruses plague PEI potato crops. The most prominent are the buckthorn aphid, Colorado potato beetle (CPB), European corn borer, green peach aphid, nematodes, potato aphid and potato flea beetle. The most common viruses/diseases in PEI potatoes are early blight, late blight, potato virus Y (PVY), common scab, dry rot, potato leafroll virus (PLRV), gray mould and bacterial ring rot. Late blight requires the largest number of chemical sprays during the PEI growing season. To fight these pests and viruses/diseases, farmers use crop rotations, integrated pest management (IPM), insecticides/fungicides and for a few years, potatoes that had been genetically modified to repel pests.

The earliest form of approved genetically modified potatoes was available to farmers from Monsanto in 1995, with the first growing season in 1996. These first modified potatoes were called NewLeaf potatoes, a Russet Burbank cultivar that was modified for resistance against CPB. The second variety of genetically modified potatoes was called NewLeaf Plus, a Russet Burbank cultivar that was resistant to CPB and PLRV. As Table 1 illustrates, both of these varieties were grown on PEI until 1999 [MacPhail 2003, Health Canada 1999a, Health Canada 1999b]. A third modified potato, NewLeaf Pro, was in development. Additional cultivars, including Atlantic, Superior, and Shepody, were reported as being in the process of modification and to have the same traits as the NewLeaf Russet Burbank potatoes [NatureMark 2004].

Table 1 - Genetically Modified Potatoes: Traits and Stage of Development

Genetically Modified Potato	Traits	Stage of Development
NewLeaf (Russet Burbank)	resistant to CPB	First approved for growth and consumption in Canada
NewLeaf Plus (Russet Burbank)	resistant to CPB and PLRV	Approved for growth and consumption in Canada in 1999
NewLeaf Y (Russet Burbank)	resistant to CPB and PVY	Approved for consumption in Canada in 1999, but never grown
NewLeaf Pro	resistant to CPB, PLRV, PVY, and late blight	In developmental stage and was to have been ready to grow by 2002

The NewLeaf potatoes could not be distinguished from other potatoes by appearance, taste, nutritional content, or cooking quality. They cost less to grow, due to the incorporation of the Bt insecticide into their genetic makeup; this means fewer insecticides needed to be applied farmers' fields to control the spread of CPB [Arsenault 2002]. Subsequent NewLeaf potato varieties were developed based on these principles, adding genes that provided resistance to PLRV and PVY.

In November 1999, McCain Foods, a world-scale food processor, sent producers a letter advising that genetically modified potatoes would not be accepted for processing in the 2000 harvest year, a move that was said to be dictated by market forces for McCain's products. This initiative is understood to have largely resulted from decisions made by major representatives of the fast food industry, who notified McCain's and Cavendish Farms that they would no longer purchase French fries made with genetically modified potatoes, due to consumer preferences.

Data yielded by field trials in PEI have shown that GM potatoes have both cost and environmental benefits. For example, if the NewLeaf Pro potato that was in the process of being genetically altered for CPB, PLRV, PVY and late blight resistance had been available and used in fields, the number of pesticide applications would be reduced by approximately 75% [Arsenault 2002]. Consequently, contamination by pesticides carried to rivers by soil erosion and runoff would have been greatly reduced, resulting in fewer fish kills [Arsenault 2002].

PROBLEM STATEMENT

Pesticides contain active ingredients and inert substances that are potentially dangerous to human health and the environment, as well as being costly farm inputs. Exposure to some active ingredients can increase the risk of contracting cancer, respiratory problems, and other health problems. Genetically modified potatoes are one potential way to reduce the exposure of the population of PEI to agricultural chemicals. This study investigates the economic effects of the loss of ability to grow GM potatoes, based on the direct financial costs to farmers and specific health costs that may be associated with this change.

REVIEW OF LITERATURE ON HEALTH EFFECTS

A damage function approach usually takes the form of translating the subject being studied (in this case, active ingredients in a pesticide released into the air during application) into a quantifiable measurement and then into measures of damage done to human health, materials, plants, animals, ecology and aesthetics by using a dose-response relationship. These effects are further translated into economic values, with externalities being identified [Matthews 2001]. Matthews (2001) notes that in practice, mortality losses dominate the health cost valuation. Damage functions can include the concepts of the cost of illness and the value of a statistical life to quantify health benefits and costs.

Cost of Illness Technique

As specified in Stratus Consulting (2001), there are a number of potential economic and social costs associated with adverse health effects resulting from air pollution. These costs can be applicable to other diseases resulting from other sources. They include:

1. Medical Costs: out of pocket expenses for the affected individual/family, costs paid by

public health care, private insurance, and so on;

2. Work loss: monetary value of lost productivity (lost income whether the affected individual is compensated for time off due to illness or not);
3. Increased costs for chores and care giving: special care giving and services that are not reflected in medical costs;
4. Other social and economic costs: restriction on/reduced enjoyment of leisure time, pain and suffering, anxiety about the future, concern and inconvenience to family members and others.

Cost of illness (COI) measures only take into consideration medical costs and lost income as a proxy for work loss and therefore do not assess the total welfare impact of an adverse health effect. Their use is generally not consistent with economic welfare theory.

Monetary Valuation of Nonfatal Cancers – Cost of Illness Approach

Willingness to pay (WTP) measures to avoid nonfatal cancers are not available, therefore the COI approach is the most commonly used to estimate such costs. The best-suited COI measure is "an incidence-based measure of the present value of the stream of costs a patient can expect to incur over the course of the illness [Stratus Consulting 2001:5-24]." This COI measure normally includes expected future health care costs, as well as loss of productivity due to illness. The alternative to this measure is a prevalence-based COI measure, which incorporates the health care costs and productivity losses that accrue to all persons with cancer in a given time period. Prevalence-based measures are not very useful for assessing the financial benefits of preventing new cases.

The COI approach is considered to give a relatively low range of values because these do not incorporate WTP measures, so that values of avoided pain and suffering and restriction of the individual from non-work activities are not captured in the COI measures [Stratus Consulting 2001].

Monetary Valuation of Fatal Cancers – Value of a Statistical Life Approach

Blomquist (2000) notes that Value of a Statistical Life (VSL) estimates have been developed in a number of studies by using evidence based on market choices involving tradeoffs between risk and money. Governments and their agencies have used these VSL estimates as a reference point for assessing the benefits of risk reduction efforts. VSL estimates are intended to show the benefits gained from risk reduction efforts as the reduced probability of death of the affected individuals and not the value of lives saved ex post. Economic literature focuses mainly on measures of willingness to pay (WTP) or willingness to accept compensation for risk of the cost of a life that are seen in labour markets, and more recently on the basis of information on price risk/price safety tradeoffs in product markets such as for automobiles and fire alarms [Viscusi & Aldy 2002].

The term "Value of Statistical Life" refers to the amount of money in dollars that an individual is willing to trade for small changes in their own probability of survival (Blomquist, 2000). For example, consider a group of 10,000 people each of whom have the same information and identical preferences. Assume it is known within this group that x people in the group will die in the next year and that if sufficient funds are raised, the group mortality could be reduced to x-1. If it was known that each person would pay $500 to reduce the mortalities by 1 person, the value of a life is taken as $500 per person times 10000 people, or $5 million. This value is normally called the value of a statistical life because the identity of the additional survivor is unknown at the beginning of the exercise (Blomquist, 2000).

FARMERS' COSTS OF REDUCED PESTICIDE USE: PARTIAL BUDGET DEVELOPMENT AND RESULTS

Assessment of the insecticides and fungicides that are approved for use in PEI potato production indicate 28 active ingredients commonly found in insecticides and 11 active ingredients commonly found in fungicides. In interviews with farmers and the PEI provincial potato specialist (conducted in Summer 2003), it was determined that the most commonly used pesticides are Senator, Admire, Lorox, Ripcord, Monitor, Dithane, Bravo, and Reglone. Table 2 summarizes information provided by these respondents, showing the pesticides that would be used in a typical growing season and their uses, as well as the recommended amount to be sprayed in each application according to the pesticide label instructions. It should be noted that potato fields would not always be sprayed in the exact manner of the spraying schedule in consecutive years, due to year to year variations in weather and pests, viruses and diseases. However, this can be viewed as a "typical" annual spraying schedule to treat potato fields for CPB, corn borer, and early and late blight, among other pest problems. This is a "best estimate" spraying schedule for NewLeaf Plus and NewLeaf Pro potatoes as the former were only grown for one year (in 1999) and the latter were not fully developed and therefore never cultivated.

Table 2: Pesticides used in a typical potato growing season, their uses, and manufacturers' recommended spraying amounts

Pesticide	Active Ingredient	Controls	Amount Sprayed
Senator	Thiophanate-Methyl	Seed piece decay	0.5 kg/100 kg seed
Admire	Imidacloprid	aphids & beetles	0.85 L/ha
Lorox	Linuron	annual broad leaf weeds	2.2 kg/ha
Ripcord	Cypermethrin	Corn borer	0.0625 L/ha
Monitor	Methamidophos	Colorado potato beetle, aphids	1.75 L/ha
Dithane	Mancozeb	early/late blight	1.1 kg/ha
Bravo	Chlorothalonil	early/late blight	1.2 L/ha
Reglone	Diquat	Topkiller	1.25 L/ha

The costs of purchasing containers of these pesticides from Cavendish Agri-Services were determined as of September 2003. The cost per spray of each pesticide was calculated based on the label recommendations, the volume of pesticide in the container and the costs of the various containers. This figure was adjusted to include non-chemical application costs, including tractor and pesticide sprayer contract costs, involving machinery rental and applicator's labour. These contract (rental) costs were obtained from Kensington Agriculture (2004) and reflect depreciation of the equipment, gasoline costs, and an estimate of the cost of time required for the farmer to operate the machinery. Seed costs of the different potatoes were also collected.

The seed and spray cost estimates for the different potato varieties[2] are the basis of partial budget estimates, given in Table 3, of changes in farmers' costs per hectare if the NewLeaf potatoes were to be grown rather than conventional potatoes. The spraying schedule used for this analysis was developed in consultation with the PEI Provincial Potato Specialist and encompasses the applications needed to combat the most common pest, virus and disease problems encountered in a given year, as listed above in Table 2.

[2] Seed costs reflect the royalty fee that Monsanto charged farmers in order to use NewLeaf seed. The relative cost of conventional seed is therefore treated as zero.

Table 3: Partial budget of farm input costs for various potatoes based on manufacturers' spraying recommendations, PEI provincial potato specialist spraying schedule, and non-chemical costs [a]

Conventional Potatoes	**Cost/ha**	**New Leaf Potatoes**	**Cost/ha**	**New Leaf Plus Potatoes**	**Cost/ha**	**New Leaf Pro Potatoes**	**Cost/ha**
Senator	$100.30	Senator	$100.30	Senator	$100.30	Senator	$100.30
Admire (IF)	$172.97	Lorox	$103.16	Lorox	$103.16	Lorox	$103.16
Lorox	$103.16	Ripcord	$46.04	Ripcord	$46.04	Ripcord	$46.04
Ripcord	$46.04	Monitor	$88.71	Bravo	$51.55	Dithane	$46.45
Monitor	$88.71	Bravo	$51.55	Bravo	$51.55	Dithane	$46.45
Bravo	$51.55	Bravo	$51.55	Bravo	$51.55	Dithane	$46.45
Bravo	$51.55	Bravo	$51.55	Bravo	$51.55	Reglone	$66.68
Bravo	$51.55	Bravo	$51.55	Dithane	$46.45	Reglone	$66.68
Bravo	$51.55	Dithane	$46.45	Dithane	$46.45		
Dithane	$46.45	Dithane	$46.45	Dithane	$46.45		
Dithane	$46.45	Dithane	$46.45	Dithane	$46.45		
Dithane	$46.45	Dithane	$46.45	Dithane	$46.45		
Dithane	$46.45	Dithane	$46.45	Dithane	$46.45		
Dithane	$46.45	Dithane	$46.45	Dithane	$46.45		
Dithane	$46.45	Dithane	$46.45	Dithane	$46.45		
Dithane	$46.45	Dithane	$46.45	Reglone	$66.68		
Dithane	$46.45	Reglone	$66.68	Reglone	$66.68		
Reglone	$66.68	Reglone	$66.68				
Reglone	$66.68						
Cost of Seed/ha			$54.40		$54.40		$54.40
Total cost of pesticide application per hectare	**$1,222.30**		**$1,103.73**		**$1,015.02**		**$576.59**

[a] Non-chemical application costs estimates per hectare are $38.80, taking into account tractor rental and pesticide applicator rental (including applicator's labour, depreciation costs and gasoline costs)

Implications of the Partial Budget

As the partial budget of Table 3 illustrates, recommended pesticide applications for the genetically modified potatoes vary only slightly between NewLeaf and NewLeaf Plus potato varieties. The recommended cultivation practices only reduce the number of pesticides applied by a minimum of one and two sprays respectively. Nonetheless, although the cost of purchasing modified seed increases farmers' costs by $54.40 per hectare, the decrease in the cost of applying chemicals results in a savings of $118.57 per hectare when growing NewLeaf potatoes and savings of $207.28 per hectare when growing NewLeaf Plus potatoes, as compared to conventional potatoes. The cost estimates per hectare and in aggregate are indicated in Table 4.

Table 4: Per hectare and aggregate savings in pesticide application costs compared to growing conventional potatoes

	NewLeaf	NewLeaf Plus	NewLeaf Pro
Savings per hectare	$118.57	$207.28	$645.71
Total savings[a]	$6 639 920.00	$11 607 680.00	$36 159 760.00

[a] Based on 1/10 of PEI's land base, being 56,000 hectares, devoted to growing the specified GM potatoes in any year,

As can be seen from Table 4, the potential to save between $6 million and $36 million on the cost of pesticide applications applies to the entire potato growing area of PEI, based on the assumption that genetically modified potatoes would be planted on all 56,000 hectares per year and that the recommended typical "best estimate" spraying schedule, shown in Table 3, prevailed.

DEVELOPMENT OF THE MODEL USED TO QUANTIFY HEALTH RISKS

In order to be able to quantify health risks from inhalation of chemical residues that remain in the air after pesticide spray application, chemicals that cause adverse health effects had to be identified. An additional requirement was for information on dose response functions by which exposure estimates could be transformed into risk estimates. Each of the active ingredients in the pesticides listed in Table 2 was evaluated for this purpose.

The chemicals were evaluated using detailed information on pesticides from two specialized website sources. The identified chemicals were initially assessed in the light of information on the Extension Toxicology Network website [EXTOXNET 1993, EXTOXNET 1996], a database service affiliated with Cornell University. This source provided the initial information needed to determine if there is danger to human health from the active ingredients, or from any of the "inert substances" added to the active ingredients in the pesticide formulations, or their metabolites. The results from this search are reported in Table 5.

Table 5: List of identified dangerous active ingredients, their origins and summary of properties

Active ingredient	Pesticide	Pesticide Control	Dangerous chemical	Summary
Mancozeb	Dithane	Early/Late Blight	Ethylenethiourea	Metabolic by-product; EPA classified as probable human carcinogen
Chlorothalonil	Bravo	Early/Late Blight	Hexachlorobenzene	inert ingredient; EPA classified as probable human carcinogen [a]
Cypermethrin	Ripcord	Corn Borer	Cypermethrin	active ingredient; EPA classified as possible human carcinogen

[a] See Cox 1997.

The United States Environmental Protection Agency (EPA) website (2004) was then consulted to determine if research for these chemicals had led to the estimation of dose response functions. The only identified dangerous chemical for which that information was available was hexachlorobenzene, as reported on the Integrated Risk Information System section of the EPA website [IRIS 1998].

Since no comparable documents expressing the dose response functions could be found for cypermethrin and ethylenethiourea, although these are also considered to be dangerous chemicals, the dose response function for hexachlorobenzene was assumed to apply also to cypermethrin and ethylenethiourea for this analysis. The actual dose response functions for these chemicals could, however, be more or less toxic than for hexachlorobenzene.

The next step in the analysis was to estimate the levels of exposure of dangerous ingredients that would apply to an applicator. Estimates for this are based on a study of pesticide air monitoring results of pesticide residues remaining in the air after a single application of an identified pesticide (chlorothalonil) conducted by the California Air Resources Board, 1986 to 1995, which is reported in Kollman (1995).

It is assumed that levels of hexachlorobenzene, cypermethrin and ethylenethiourea could be detected at the same levels as chlorothalonil after a single application of pesticide. The information given in Kollman (1995) illustrates that for every single spray of pesticide containing chlorothalonil, there are at least three days of exposure to concentrations that are detectable. Again, actual levels of air-borne residues that applicators and others are exposed to could be more or less concentrated than assumed.

It is also assumed that residues on food are zero/undetectable for all pesticide active ingredients and that the affected population is not exposed to the chemicals through water or soil. Finally, each spray is assumed to be applied at least three days apart so that there is no overlap between sprayings. That is, each spray is taken to be equal to three days of exposure.

Following Health Canada (1995), the estimated dose was calculated as:

$$ED = \frac{CR * C * EF}{BW} \qquad (1)$$

where ED is the estimated dose; CR is the inhalation rate (a standardized value is $20m^3$/day, over a lifetime of 70 years [Jardine 2004]); C is the concentration of the chemicals in mg/m^3; EF is the exposure frequency, and BW is bodyweight (a standardized weight of 60kg is assumed [Jardine 2004]). The ED is taken as the estimated daily intake (EDI) of the chemical[3].

To calculate the risk associated with the level of exposure, the EDI is multiplied by the slope factor of the dose response function for hexachlorobenze, which is 1.6[4]. Resulting risk estimates are summarized in Table 6.

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[3] Due to lack of data detailing exposure from other sources; inhalation exposure is the only exposure route evaluated; ideally, an EDI estimate would take into account exposure from inhalation, ingestion, water and soil.

[4] In Health Risk Assessment theory, exposure to one molecule of the identified dangerous substance is considered enough to cause the mutation that would be the onset of cancer. This indicates that the dose-response function passes through the origin. The slope of that dose-response curve can then be calculated, and is subsequently used to calculate the risk level associated with exposure to that chemical [Jardine 2004].

Table 6: Estimated daily intakes (EDI) and subsequent risk estimates for chosen concentration rates (in mg/m^3)[a] under Conventional/NewLeaf/NewLeaf Plus and NewLeaf Pro growing practices

Concentrations	Conventional/NewLeaf/NewLeaf Plus Growing Practices[b]			NewLeaf Pro Growing Practices		
	EDI	Risk	1/x [c]	EDI	Risk	1/x
0	0	0		0	0	
1.6677E-5	5.9E-7	9.5E-7	1052718	1.8E-7	2.9E-7	3417334
3.3354E-5	1.19E-6	1.9E-6	526359	3.7E-7	5.9E-7	1708667
6.6708E-5	2.37E-6	3.8E-6	263180	7.3E-7	1.17E-6	854334
1.58E-4	5.62E-6	9.0E-6	111115	1.73E-6	2.77E-6	360702

[a] Average values were taken from the study of Kollman (1995) and were used to represent the range of concentrations that the affected population could be exposed to.
[b] Although the number of pesticide sprays used in NewLeaf and NewLeaf Plus growing practices are reduced relative to Conventional potato growing practices, the sprays containing the identified dangerous chemicals are not reduced. Therefore, the risk of contracting cancer from the sprays used under these particular growing practices is identical.
[c] 1/x represents, for e.g., a situation where one person in 111,115 will contract cancer with the EDI of 5.62E-6.

The risk estimates were then used to calculate estimates of the annual monetary value of nonfatal and fatal cancer that each exposed individual is expected to be willing to pay in order for pesticides not to be applied at the recommended rates. The estimates of values of illness were taken from the Royal Society of Canada Publication "AQVM Companion Manual to the Report of an Expert Panel to Review the Socio-Economic Models and Related Components Supporting the Development of Canada-Wide Standards for Particulate Matter and Ozone" [Stratus Consulting 2001], and were incorporated into the following equations:

Annual Value of Nonfatal Cancer = $305,000 * Risk * Survival Rate (2)

Annual Value of Fatal Cancer = $4,300,000 * Risk * Death Rate (3)

where the value of $305,000 is the central value of illness for nonfatal cancer and $4,300,000 is the central value of illness for fatal cancer, as given by Stratus Consulting (2001); the survival rate is an average survival rate for liver, lung and thyroid cancer, expressed as a percentage; and the death rate is 1 minus the survival rate, expressed as a percentage [Gloeckler Ries 1994].

Initially, health effects are estimated for the applicator, in this case the farmer, and their families only. There are 650 potato farmers in PEI, and an average family size of four people is assumed. This particular estimation assumes that all four people in the farm family, but no one else, are exposed at identical inhalation concentrations of the chemical after it has been sprayed, over a time period of three days. However, as explained in the following section, the potato production area of PEI is geographically close to the entire PEI population, so that a second estimation is conducted in which it is assumed that all PEI residents are exposed to the chemicals.

Impact of Pesticide Drift on Health Costs

There is potential for drift of the sprayed chemicals, which raises the possibility of health effects on other community members than farmers and their families. From a study conducted for the Government of California [Majewski & Baston 2002], there is a clear indication that air samples taken in a 50 to 70 km radius circle from the spraying field contain traces of the active pesticide ingredient chlorothalonil. Air concentrations from three locations were tested for chlorothalonil in that study. The drift residues were measured in ng/m^3 and their presence was concluded to be partially dependent on wind speed and wind direction. It is assumed that testing for hexachlorobenzene, cypermethrin and ethylenethiourea drift would give similar results to those found in the California study for chlorothalonil. These air concentrations would carry a risk of contracting cancer based on lifetime exposure. Prince Edward Island is a small island and potato fields normally extend up to property edges, with no buffer zone between houses and the fields. Due to the distance that the drift can travel, and the distribution of farms on the land base of Prince Edward Island, it is assumed that every person within a 50 km radius of where the pesticide is sprayed will be exposed to the chemical active ingredient of the pesticide, although the time frame of exposure is not known. For this analysis, the time period of exposure is assumed to be one day per pesticide spray. The estimated health benefits from reduced pesticide exposure associated with modified potatoes are given in Table 7.

RESULTS AND DISCUSSION

As indicated in Table 7, the aggregate estimates of annualized health benefits for the assumed affected farmer population to grow NewLeaf Pro potatoes ranges between $4,732.00 and $44,824.00, depending on the level of exposure to which the affected population is subject[5]. These numbers are not overly large, in that they represent a per person annualized benefit of $1.82 to $17.24. Health benefits realized when the entire population of Prince Edward Island is considered range from $87,000 to $821,000. These benefits are more significant than the savings realized when farmers alone are assessed, but still do not represent a large portion of the overall benefits from modified potatoes, as compared to the savings from reduced chemical input use.

Table 7: Annualized reduction in costs of illness using spraying schedule recommended by the provincial Potato Specialist and frequency of pesticide sprays under NewLeaf Pro growing practices for both the farmer population and entire population of Prince Edward Island

			Concentration Rates in mg/m^3 NewLeaf Pro [a] Growing Practices			
Illness	Cost of Illness	% [b]	1.6677E-5	3.3354E-5	6.6708E-5	1.58E-4
Nonfatal Cancer	$305,000.00	38.3	$0.01	$0.02	$0.05	$0.11
Fatal Cancer	$4,300,000.00	61.7	$0.26	$0.52	$1.04	$2.46
Farmer Health Benefits realized when growing NewLeaf Pro potatoes [c]			$4,732.00	$9,464.00	$18,902.00	$44,824.00
Total Health Benefits realized when growing NewLeaf Pro potatoes [d]			$87,290.01	$173,226.61	$346,427.22	$821,681.34

[a] Note that this potato was in promising stages of development, but never tested or grown. The values expressed in this section are based on the "best estimate" spraying schedule developed by the Provincial Potato Specialist. Additionally, the values of illness are based on total population exposure of one day per pesticide spray. The farmer health savings are calculated based on three days of exposure per pesticide spray. [See White 2004 for further information.]

[b] % refers to the proportion of the population who survive cancer (nonfatal cancer) and die from cancer (fatal cancer).

[c Health] Benefits refer to the reduced health costs encountered when growing NewLeaf Pro potatoes. The farmer population consists of the 650 potato farmers and their immediate family (assuming 4 people per family unit), for a total of 2600 people.

[d] The total health benefits take into account the farmer population of 2600 people, and the remaining population of PEI (137,941 less 2600 farmers, as per Statistics Canada, October 1 2003), who could be exposed to the chemicals through pesticide drift.

To place the health benefit estimates to farmers in context, relative to their cost savings from lower pesticide applications for modified potatoes, it is necessary to convert the health benefit estimates to measure the average health benefit per hectare. For this

[5] It should be noted that, in this section when the word "Conventional" is used, this refers to Conventional, NewLeaf and NewLeaf Plus potatoes, as the number of sprays containing the identified dangerous active ingredients for these varieties are the same. This occurs because the dangerous chemicals are used to control early/late blight and NewLeaf Pro potatoes are the only genetically modified potatoes that were to have these traits.

purpose, the total health benefit estimates to farmers and their families were divided by the number of hectares that potatoes are seeded to each year. That is,

$$\text{Health benefit per hectare}_{(farmers)} = \text{Total farmer health benefits}/56000 \text{ hectares} \quad (4)$$

Assuming that maximum exposure levels apply (and therefore assuming the maximum monetary costs of illness to farm families), the annual benefit to farm family health, expressed on a per hectare basis, from growing NewLeaf Pro potatoes, is 80¢. There are no health benefits from reduced cancer incidence of NewLeaf or NewLeaf Plus potatoes. The market-level partial budget benefit estimates of Table 4, which considered only the cost savings in terms of pesticide application costs, are included in Table 8, as are the non-market health benefits to farm families of the modified potatoes, as developed under the assumptions of the study.

Table 8: Per hectare benefits overall to farm families from growing genetically modified potatoes as compared to growing conventional potatoes

	Conventional	NewLeaf	NewLeaf Plus	NewLeaf Pro
Pesticide Cost Reduction	$0	$118.57	$207.28	$645.71
Health Benefits[a]	$0	$0	$0	$0.80
Total Benefits	$0	$118.57	$207.28	$646.51

[a] Health benefits for farm families are at the maximum exposure level and these are only found when NewLeaf Pro potatoes are grown, due to the decrease in spray frequency of identified dangerous chemicals.
[b] Pesticide cost reductions encompass the reductions in chemical and non-chemical application costs; royalty fees Monsanto charged for the use of its seed are considered in these estimates.

It can be seen from Table 8 that the estimated health benefits to farm families of less pesticide use from the genetically modified potatoes are much smaller than the financial savings from reduced pesticide use. The most significant cost benefits to PEI farmer applicators are found to apply when growing NewLeaf Pro potatoes, which give estimated aggregate savings of $36,170,400.00. These potatoes might or might not perform as assumed. However, there is the possibility that they could have exceeded expectations and outperformed the original assumptions or that Monsanto could have improved upon the technology and created another modified potato that outperformed the expected performance of NewLeaf Pro potatoes. The estimated annualized aggregate health benefits for the farmer population when growing NewLeaf Pro potatoes are a maximum of $44,824.00, which is only 0.12% of the total savings, whereas the annualized savings from pesticide reduction represents 99.88% of the total net benefits. Comparing the benefits realized when growing NewLeaf potatoes ($6,639,920.00) and NewLeaf Plus potatoes ($11,607,680.00), estimated annual savings in pesticide costs are more than tripled for NewLeaf Pro potatoes.

CONCLUSIONS

This study used a partial budget to estimate the savings from the reduced use of chemicals found when growing genetically modified potatoes. For this purpose, a dose response function for hexachlorobenzene reported by the EPA was used and was applied to two other chemicals classified by the EPA as "probable/possible carcinogens", all of which were active or inert ingredients or a metabolic by-product of pesticide formulations used in potato production in Prince Edward Island. By calculating risk estimates of exposure to specified concentrations under Conventional/NewLeaf/NewLeaf Plus and NewLeaf Pro growing practices, and combining these estimates with health cost information derived through Cost of Illness and Value of Statistical Life techniques, estimates of health benefits were calculated for PEI farmer applicators, as well as their families. Estimates of the health benefits to others in PEI from reduced pesticide application were also derived, based on evidence from chemical drift reported from California.

Using the assumptions set out in the development of the model, the results indicate that the annualized monetary health savings for the assumed affected population of farmer applicators and their families when growing NewLeaf Pro potatoes ranges from $4,732.00 to $44,824.00. These estimates are based on scenarios in which farmers grow NewLeaf Pro genetically modified potatoes as opposed to Conventional potatoes. The estimates depend on the level of exposure to which the affected population is subjected.

While the health benefits from reduction of air-borne pesticide inhalation from growing NewLeaf Pro potatoes are quantifiable, they are not as significant as one might have thought[6]. This is highlighted by the comparison of health benefits to the monetary benefits from input cost savings that farmers would experience when growing genetically modified potatoes, due to the reduction in chemical inputs. These savings range from $6

[6] For example, reduction of incidents of farmer poisoning has been concluded to be a major non-market benefit from the use of pest resistant cotton in China, a developing country (Pray, 2002).

million to $36 million per year, depending on the type of genetically modified potato grown.

Pesticide drift has long been a topic of concern for environmental groups and others, including government. Use of information from a California assessment of pesticide drift in relation to PEI leads to the conclusion that the entire population of PEI could be at a very small increased risk of contracting cancer over a lifetime of exposure. If NewLeaf Pro potatoes were grown on all potato producing land in the province, the health risks to the entire population of PEI would be reduced, relative to the health risks incurred in growing Conventional potatoes. However, the monetary value of this risk reduction is relatively small expressed per person and also in aggregate (reflecting the relatively small population of PEI). The aggregate costs of pesticide drift could be higher in more highly populated regions of intensive potato farming, such as in New Brunswick, Idaho, or other major potato producing regions in the United States.

The results of this study show that private financial benefits from GM potatoes appear to be large relative to non-GM potatoes, but that reductions in health risks associated with GM potatoes, either to farm families or to the population of PEI, appear to be negligible. While the study documents the health risk reductions to human populations, it does not comment on impacts on ecosystems and wildlife populations. It also ignores the potential effects associated with pesticide resistance which could complicate the problem significantly. Furthermore, it does not investigate the health consequences of consumption of GM potatoes relative to non-GM potatoes. These other aspects of the situation are interesting avenues for future research.

The benefits from reduced chemical use applied in this paper are fairly straightforward, but the analysis would be strengthened by information from air residue concentration measurement and epidemiological assessment and monitoring in areas of intensive pesticide applications. Information that would enable rigorous analytic assessment of the environmental consequences of pesticide application is lacking. There are reported instances of fish kills in period of high rainfall that are anecdotally related to pesticide use in PEI, but there is a lack of data to assess this non-market cost of pesticide use. These are areas of further research that would contribute to more accurate analysis of the benefits and costs of the use of genetically modified potatoes in PEI and elsewhere.

Such studies would aid future policy decisions and consumer education and awareness in relation to the costs and benefits of both pesticide use and genetically modified crops.

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