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THE ECONOMIC AND ENVIRONMENTAL IMPACTS OF INVESTMENTS IN THE DEVELOPMENT AND ADOPTION OF GENETICALLY MODIFIED POTATO

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Abstract

Potato, maize, rice and wheat, are the four major food crops in the world. Since potatoes produce more calories and more protein per hectare than the other three major crops it is an important commodity for fighting hunger in developing countries. Researchers at the International Potato Center in Peru predict that third world potato use will more than double by 2020. Potatoes are also popular in developed countries, with per capita consumption exceeding 100 kg per year in some European countries.

Potato production is risky and input intensive. Since potato growers plant tubers rather than true seed, the risk of seed-borne disease is substantial. This vegetative propagation method means that each potato plant is a clone of the mother plant and diseases are easily passed and spread to succeeding generations. Farmers rely on pesticides to protect potato crops from a multitude of pests. Potato growers in the United States apply about 70 million pounds of pesticides each year. Growers and consumers are interested in potato production practices that use fewer pesticides, are environmentally friendly and produce ample supplies of potatoes at low costs. Planting potatoes that have been genetically modified to resist pests is a practice that offers hope to growers and consumers around the world.

Monsanto developed the first genetically modified potato approved for commercial markets. Known as New Leaf Russet Burbank, the potato includes a protein from a naturally occurring soil bacterium, *Bacillus Thuringiengsis* (Bt) that controls Colorado Potato Beetle (*Leptinotars decemlieata*). Monsanto's next product, New Leaf Plus, was genetically modified to control potato leafroll virus (PLRV), which is commonly spread by the Green Peach Aphid

(*Myzus persicae*). PLRV can cause net necrosis, a serious potato quality problem. Monsanto and other public and private institutions are trying to genetically modify potatoes to control other pests such as potato late blight (*Phytophthera infestans*) and nematodes. Public acceptance has slowed the marketing of the existing, and yet to be developed genetically-modified potatoes.

The objective of this study was to estimate the economic and environmental impacts of genetically altered potatoes. The analytical tool used is an ex ante benefit-cost model with a probability distribution. Expert opinion from potato scientists in the United States provides much of the data for the model. Potato experts provided information via a Delphi survey regarding the reduced use of pesticides, changes in production practices, impacts on yields and changes in potato quality that could be attributed to potatoes that are genetically altered to control various potato problems. Results suggest that the potato industry and society in general would gain significant economic benefits with reduction in active toxic material, if genetically altered potatoes were adopted by growers and accepted by consumers.

The estimated annual gross benefit attributed to the development and adoption of a genetically modified late-blight-resistant potato for the major potato-producing regions of the world is over $4.3 billion. The estimated present value of the flow of annual gross benefit projected over 25 years productive life expectancy of the variety and estimated probability of adoption is over $27 billion. The annual present value to producers and consumers of potato is over $1.082 billion. In addition to the economic benefit, the adoption of the genetically modified potato will eliminate the use of an estimated 41,154,274 kg of active toxic chemical ingredients.

THE ECONOMIC AND ENVIRONMENTAL IMPACTS OF INVESTMENTS IN THE DEVELOPMENT AND ADOPTION OF GENETICALLY MODIFIED POTATO

Introduction

Potato, along with maize, rice and wheat, is one of the four major food crops in the world. Since potatoes produce more calories and more protein per hectare than the other three major crops, it is becoming an increasingly important commodity for fighting hunger in developing countries (Niederhauser, 1993). Researchers at the International Potato Center in Peru predict that developing countries consumption of potato use will more than double by 2020. Potatoes are also popular in developed countries, with per capita consumption exceeding 100 kg per year in parts of Europe.

Potato production is risky and input intensive. It is among the highest user of synthetic pesticides in agriculture. Farmers rely heavily on pesticides to protect potato crops from a multitude of pests. An estimated 120 pounds of synthetic pesticides per acre are used annually to control pests on potatoes in the United States (U.S.). Growers and consumers are interested in potato production practices that use fewer pesticides, are environmentally friendly and produce ample supplies of potatoes at low costs. Planting potatoes that have been genetically modified to resist pests is a practice that offers hope to growers and consumers around the world.

The first genetically modified potato that was developed and approved for commercial markets is the variety known as New Leave Russet Burbank that is resistant to Colorado Potato Beetle and Leafroll virus (PLRV). Public and private researcher institutions are genetically modifying potatoes to control potato late blight. The disease has devastated potato production for the last century and a half. Niederhauser (1993) claims it is the most important potato disease in the world. Because of the variability and virulence of the fungus *(Phytophthora infestans*) that causes late blight, durable resistance to the disease is difficult to incorporate into commercial potato cultivars with traditional breeding practices. In recent years, growers have effectively controlled late blight with fungicides, but at a high cost. Blight control costs in some areas in the U.S. exceed 10 percent of total production costs (Stevenson, 1993).

Limited research has been conducted on the economic impact of potato late blight. Knutson et al. (1993) concluded that Maine potato yields would decline 25 percent if fungicide applications were cut in half and that late blight would wipe out the entire Maine potato industry if fungicides were unavailable. More recently, Guenthner et al, (1999) found that late blight was the most serious disease problem in the US potato industry and that the loss of chlorothalonil, a late blight treatment, would cost the industry $80 million per year.

The objective of this study was to estimate the economic and environmental impacts of genetically modified potatoes that are immune to late blight. Although the impacts of late blight go beyond the farm, we did not estimate impacts on other enterprises or consumers.

Data

Data on increase in yield, reduction in storage loss, and reduction in fungicide use, attributed to the development and adoption of the genetically modified potato variety that is resistant to late blight, were obtained from a survey of potato scientists in the U.S. The Delphi technique was used to obtain expert opinion from thirteen University scientists who are knowledgeable about potato late blight (Guenthner, Michael and Nolte, 2001). Delphi surveys consist of two or more rounds. Researchers provide participants with group averages and their own answers to previous-round questions. With this new information they ask respondents to again answer the questions, leading to a group consensus. Rasp (1973) found that anonymous responses were more likely to be objective. By not being in the same room, participants are more confident in contributing their opinion and do not feel pressured by a dominant group leader (Linstone & Turoff, 1975).

Respondents were chosen based on their knowledge of potato late blight, the fungicides used to control it and their willingness to participate. Electronic mail was selected as the method of questionnaire distribution for the participants' and facilitators' convenience. The questionnaire asked participants to estimate changes in yield, storage loss, and fungicide use if the late blight's potato resistance variety is adopted. The experts were asked to answer the questions from the perspective of the impact on the entire potato industry rather than the geographical area in which they work.

Average responses for second-round responses were quite close to first round responses. For yield loss and metiram use the average responses were identical. The range of answers narrowed for all questions between the two rounds. Relatively wider ranges persisted for some fungicides, suggesting differences in local conditions. Although respondents were asked to consider the entire US potato industry, some indicated that their answers were influenced by local conditions. Since the average answers remained stable, the survey was concluded after two rounds.

Results of the Delphi survey show that adoption of the genetically modified late-blight-resistant potato variety would increase yield by an estimated 5 percent and reduce present storage loss of the potatoes requiring storage by 17 percent. Wiese et al. (1999) shows that blight control improves quality by reducing the percent of potato rejection and price discount. The quality improvement will reflect in a 3.2 percent increase in the value of sale.

The Delphi survey results show that adoption of the genetically modified potato variety will significantly reduce fungicide application resulting in 3.98 percent reduction in the baseline line active toxic ingredients, depending on the type of fungicides (Table 1). Estimated fungicides cost to control late blight in the U.S. is $77.1 million annually. It is based on survey results and United States Department of Agriculture (USDA) data. For the first eight fungicides shown in Table 1, USDA chemical use surveys (1990-98) and USDA annual price summaries (1990-98) were used to calculate baseline values. Since the last three fungicides were not included in the USDA sources, use data came from the Delphi survey and price data from the University of Idaho (Patterson, 1998). USDA chemical use surveys after 1998 were deemed too limited in scope regarding potatoes to provide updated data for this study.

Data on area planted, yield, production, and storage by potato producing regions of the world is shown in Table 2. Critical assumptions regarding the timetable of late-blight resistant potato development and adoption rates were based on a technology adoption rate paper by Guenthner (2001). The pattern of adoption is typical of a product life cycle consisting of four stages: introduction, growth, maturity and decline. The time horizon used in this analysis is to year 2025 when the market has reached maturity but not decline (Table 3).

Evaluation Methods

The contribution of research to productivity growth in agriculture is well documented for the U.S. and other countries. Returns to investments in agricultural research have been estimated for most major commodities with the exception of the potato. The estimated rate of return ranges from –47.5 percent to investment in wheat research in Bolivia, to 700 percent to investment in hybrid corn research in the U.S. (Arndt, Dalymple, and Ruttan, 1977; Araji, 1980; Norton and Davis, 1981; and Echeverria, 1990). The two approaches used to evaluate the benefit of investment in agricultural research 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 (Araji, 1980; Norton and Davis, 1981; Alston, Norton and Pardey, 1995).

The *ex-post* approach evaluates past research performance. The two principle methods used in *ex-post* research evaluation are: (1) production function, and (2) index-number. The production function method estimates the contribution of research in term of its impact on improved production efficiency, and it estimates marginal rates of return. The production function method 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 variatal development and management practice research in the U.S. Araji (1989) used the Cobb-Douglas production function to evaluate the benefit of investments to wheat research in the western United States. Araji, White, and Guenthner (1995) used the supply response model to analyze the spillover effects of potato research in six U.S. potato-producing regions. Araji and White (1996) used Vector Autoregressions model, with time series and cross sectional data, 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, an elasticity of demand coefficient, and an elasticity of supply coefficient. This 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 Extension Program to producers and consumers of milk and milk products. Araji and White (1990) used the index-number method to estimate the benefit of research to U.S. wheat producers and domestic and international consumers of U.S.

wheat. Also, Araji and White (1991) used the index-number method to assess the multi-market effects of technological changes and benefit of research to consumers and producers of beef and pork in the U.S.

The *ex-ante* approach evaluates future research performance, and projects flow of future benefits and cost expected from the development and adoption of research results. The four principle methods used in the *ex-ante* approach are: (1) benefit-cost method, which estimates rate of return, (2) scoring method, 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 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 rate of adoption and estimated rates of return to research and extension investments in nine major commodities in the western United States. Araji (1981) used a similar *ex-ante* approach to estimate return to investment in integrated pest management for 20 major agricultural commodities in the 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 to analyze the focus, function, and the productivity of the state agricultural experiment station system.

The Economic Model

Given the nature of the problem and the projected flow of future benefits in this study, *ex-ante* approach, is the only appropriate evaluation procedure. An *ex-ante* benefit-cost model with probability distribution was developed to estimate annual gross benefits and project present value of future flow of annual gross benefits resulting from the development and adoption of the genetically modified potato variety. The model is outlined in a set of equations in this section.

The annual gross benefit is estimated using Equation 1.

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

Where:

β_{jt} = the benefit accruing to the genetically modified potato variety in the j^th^ region in year t

A_{jo} = the expected total production or acreage affected by the adoption of the genetically modified potato variety in the j^th^ region in the base year

j = 1-N regions in the world

ΔP_{jt} = the expected percentage change in net productivity, quality, production cost and/or loss of potatoes due to the adoption of the genetically modified variety in the j^th^ region in year t. Net productivity change is defined as net increase in production in tons per hectare; quality change is defined as net reduction in rejection and price discount; production cost is defined as net decrease in pesticide cost, and loss is defined as net decrease in storage loss.

V_{jt} = the expected price received per tons of potato in the j^th^ region in year t, and

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

where f is the flexibility ration and V_{jo} is the price per unit of potato in the base year. The flexibility ratio is the inverse of price elasticity and it gives the percentage change in price associated with 1 percent change in quantity. Guenthner (1987) calculated a flexibility ratio of 0.83 for potato. Haung (1991) calculated flexibility ratios for several food products and shows a flexibility ratio of -0.7053 for potato.

β_j is the benefit that accrues to producers as a result of adopting the genetically modified potato variety. The outcome β_j is probabilistic because it depends on the probability of successful development and adoption of the variety, $P(A \cap S)$. The expected value of β_j is defined as:

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

The present value of the expected flow of future benefits from the adoption of the j^th^ variety is calculated by "discounting" the right-hand side of Equation 2 as shown in Equation 3 below.

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

Where:

$PE(\beta_j)$ = present value of the expected flow of benefit in the j^{th} region

r = the social discount rate

T = number of years for which the genetically modified potato variety affects production, quality, and/or cost

The probability of research success is estimated at 100 percent. Based on the Delphi survey results and the paper by Guenthner (2001), the probability of adoption of the genetically modified potato variety is projected for 25 years and is shown in Table 3. A 6 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 in the U.S. A 25-year productive life expectancy of the modified variety is estimated in consultation with the potato researchers, extension specialists, and potato farmers. It is assumed that a better technology will likely be available after 25 years. Since the costs of development of the genetically modified potato incurred by public and private research institutions were not made available to the authors, the present value of flow of costs are not analyzed in this study.

Environmental model

The environmental benefit attributed to late blight resistance is the elimination of fungicide sprays. The amount of active toxic materials expected to be eliminated from the environment in each region of the world is estimated by the following equation:

$$\mathrm{ATM}_{ji} = \{(\mathrm{AC}_j)\ (\mathrm{I}_{nj})\ (\mathrm{A}_{dj})\ (\mathrm{P}_{jt})\ (\mathrm{GL}_{ji})\ (\mathrm{Tx}_i)\ (\mathrm{P}/\mathrm{GL})_i\}\{\mathrm{P}(\mathrm{A})\} \qquad (4)$$

Where:

ATM_{ji} = active toxic material in i^{th} late-blight fungicide used in the j^{th} region

AC_j = total hectares of potatoes in the j^{th} region

I_{nj} = percentage of plantings currently susceptible to late-blight in the j^{th} region (100 %)

A_{dj} = percent of I_{nj} plantings that require fungicide spray used to control late blight in the j^{th} region (100%)

P_{ji} = percentage of A_{dj} using the i^{th} late-blight fungicides in the j^{th} region (100%)

GL_{jt} = fungicide application rates per hectare in the j^{th} region in year t

Tx_i = percent of active toxic materials in each fungicide

Results and Discussion

Gross Benefit

Annual gross benefits attributed to the development and adoptions of the genetically modified potatoes are shown in Table 4 for regions of the world. Annual gross benefits are calculated as the contribution of the genetically modified variety to increase in yield, reduce storage loss, improve quality, and reduce fungicide cost. For all regions of the world, it was estimated that the adoption of the genetically modified potato variety will increase yield by 5 percent, reduce storage loss by 1.241 percent and improve revenue by 3.2 percent due to reduction in potato rejection and price discount.

It is estimated that the adoption of the genetically modified potato variety will reduce fungicides cost by \$136 per hectare for Europe, North and Central America, and the Oceania regions of the world. For Africa, Asia, and South America, the reduction in fungicides cost is estimated at \$68 per hectare as these regions use less fungicides for late blight control.

The estimated annual gross benefits worldwide attributed to the development and adoption of the genetically modified potato exceeds \$4.3 billion. Europe will have the highest annual gross benefit of \$1.936 billion, followed by Asia with \$1.587 and North and Central America with \$0.369 billion. The United States accounts for 90 percent of the annual gross benefit of North and Central America.

Present Value

The present value of future flow of annual gross benefit is projected over 25 years using 6 percent social discount rate and the probability of adoption shown in Table 3. The present value attributed to the development and adoption of the genetically modified potato is estimated at over \$27 billion to potato producers in the world at an annual value of \$1.082 billion (Table 5).

European producers of potato will benefit the most from adopting the genetically modified potato. The present value of annual gross benefit to European producers of potato over 25 years is estimated at over $12.196 billion at an annual value of over $487.84 million. Asian producers of potato will benefit by over $1.225 billion over 25 years of adoption at an annual rate of over $49 million. United States producers of potatoes will benefit by a total $2.117 billion at an annual benefit of over $84.696 million. In general, the development and adoption of the genetically modified potato will benefit all potato producing regions of the world.

Environmental Benefit

The development and adoption of the genetically modified potato will eliminate significant quantities of active toxic ingredients from the environment. An estimated 25,604,958 kg of active toxic ingredients will be eliminated annually from the European environment. North and Central America's environment will have 2,275,268 kg less active toxic ingredients annually. Active toxic synthetic chemicals in the Oceanic environment will be reduced by 150,172 annually. Asian potato producing countries will eliminate 10,276,144 kg of active toxic synthetic ingredients from contaminating their environment annually. South American potato producing countries will eliminate 1,507,767 kg of active toxic ingredients from their environments annually. In general, potato-producing countries of the world are expected to eliminate over 37,520,216 kg of active toxic synthetic ingredients from the world's environment annually by adopting the genetically modified potato variety (Table 6).

Chemical costs of late blight control represent only about one-quarter the total estimated cost of this disease to the grower. In spite of the availability of effective fungicides, late blight still causes serious losses in production, storage and quality. The absence of late blight would reduce, but not eliminate, fungicide use in potato production. Metalaxyl use would decrease by only 3% because growers apply it to control pink rot (*Phytophthera erythroseptica*) and pythium leak (*Pythium spp.*). Growers would also continue to use other fungicides, such as metiram, triphenyltin hydroxide, cholorthalonil and copper hydroxide to control early blight (*Alternaria solani*).

Costs of non-fungicide control practices were not analyzed. Experts recommend that growers plant certified seed, destroy potato dumps, reduce volunteer potato populations, and maintain plant health to help control late blight. The costs of these practices were not estimated because even if late blight did not exist, the same measures would be recommended to control other diseases.

Summary

Potato, along with maize, rice, and wheat is one of the four major food crops in the world. However, potatoes produce more calories and more protein per hectare than the other three major crops. It is gradually becoming an important food commodity for fighting hunger in the world. It is projected that developing countries consumption of potato will more than double in 2020.

Agricultural land planted with potatoes has been increasing in all potato producing regions of the world. In 2000, over 18.76 million hectares of agricultural land in the world were planted with potatoes with a total annual production exceeding 311.287 million metric tons and a total farm value of over $32 billion. Europe is the largest potato-producing region of the world, accounting for 48.74 percent of the land planted with potato and 45.22 percent of the total production.

The developing regions of Africa, Asia, and South America have 8,749,251 hectares of agricultural land planted with potatoes, representing 47 percent of the world's total. These regions produce 138,510,299 metric tons of potatoes annually, accounting for 44 percent of the world's total potato production.

Results of field trials and the Delphi survey show that elimination of late blight as a potato pest would increase yield by 5 percent, reduce storage loss by 17 percent, reduce rejection and price discount by 3.2 percent, and reduce fungicide costs. An estimated probability of adoption over 25 years enabled estimates of future benefits. An *ex-ante* benefit-cost model with probability distribution was used to estimate annual gross benefit and project the present value of future flow of annual gross benefit attributed to the adoption of the genetically modified potato.

Annual gross benefits attributed to the impacts of the genetically modified potato variety on increase yield, reduce storage loss, improve quality, and reduction in fungicide cost is estimated at over $4.3 billion, based on 25 years probability adoption by potato producers in the world. The European region will have the highest annual gross benefit of over $1.936 billion followed by Asia with over $1.587, North and Central America with $369.6 million, Africa with $192.2 million, and South America with $189.3 million.

The present value of the flow of annual gross benefits discounted by 6 percent social discount rate over 25 years period projected probability of adoption is over $27 billion for potato producers of the world at an annual benefit of over $1.082 billion. The present value of the flow of annual gross benefit to European producers of potato is over $12.196 billion at an annual value of over $487.84 million. Asian potato producers will benefit by a total of $10.001 billion at an annual value of over $400 million. Potato producers in North and Central America will benefit by a total of $2.341 billion at an annual value of over $93.649. Potato producers in Africa and South America will have a total benefit of $1.225 billion and $1.207 billion, respectively.

The adoption of the genetically modified potato will have a significant environmental impact. It will eliminate the use of over 41.154 million kg of active toxic ingredients annually and thus enhance the environments of all potato producing regions of the world. The adoption of the genetically modified potato by European producers of potato will eliminate the use of over 25.6 million kg of active toxic materials annually. The Asian environment will be enhanced by a reduction of over 10.276 million kg of active toxic ingredients. North and Central America potato producers will eliminate the use of over 2.275 million kg of active toxic ingredients followed by South America with 1.5 million kg, and Africa with 1.34 million kg.

In general, the development and adoption of the genetically modified potato will have significant economic benefits to producers of potatoes in all regions of the world plus a very positive environmental impact.

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Table 1: Fungicide baseline use of active toxic ingredient and percent reduction in use due to the adoption of genetically modified potato variety, U.S.

Fungicide:	BaselineUse (1000 kg)	Percent Reduction (percent)	Total Reduction (1000 kg)
Chlorothalonil	1,595	33	526
Copper ammonium	2	54	1
Copper hydroxide	95	51	48
Mancozeb	1046	26	272
Maneb	221	26	57
Metalaxyl	27	3	1
Metiram	125	32	40
Triphenyltin hydroxide	38	44	17
Cymoxanil	327	98	321
Dimethomorph	200	98	196
Propamocarb	114	98	112
Total	3,790	-	1,591
Per hectare	6.7	-	2.8

Source: Guenthner et al., (1999) and Wiese et al., (1999)

Table 2: Area planted, yield, production, and storage by potato producing region of the world

Region	Area Planted (ha)	Yield (ton/ha)	Production (ton)	Price (ton/ha)	Storage Loss (ton)
Africa	893,310	11.32	10,109,857	137.67	1,447,204
Asia	6,850,763	16.53	113,256,129	104.88	8,333,445
Europe	9,144,628	15.39	140,768,746	98.90	15,579,903
N & C America	812,596	37.14	30,178,515	110.34	3,149,277
Oceania	53,633	34.12	1,829,781	133.67	37,013
South America	1,005,178	15.07	15,144,313	84.61	1,446,685
World total	18,760,108	16.59	311,287,579	102.66	31,074,122
USA	546,980	42.79	23,404,000	115.34	1,870,000

Source: Food and Agricultural Organization of the United Nations, 2000.

Table 3: Projected adoption profile for genetically modified potato

Year	Probability of adoption (percent)
2004	4
2005	8
2006	12
2007	16
2008	20
2009	25
2010	34
2011	46
2012	57
2013	65
2014	74
2015	76
2016	78
2017	79
2018	80
2019	81
2020	82
2021	83
2022	83
2023	83
2024	83
2025	83
2026	83
2027	83
2028	83

Source: Delphi Survey and Guenthner (2001)

Table 4: Potato value and annual gross benefit attributed to the development and adoption of the genetically modified potato variety by region of the world, 2000.

Region	Total Annual Value (m.$)	Annual Gross Benefits in Million $				Total
		Yield Increase	Reduce Storage Loss	Improve Quality	Reduce Fungicides Cost	
Africa	1,391.9	69.6	17.3	44.5	60.7	192.2
Asia	11,878.2	593.9	147.4	380.1	465.9	1,587.3
Europe	13,921.8	696.1	172.8	445.5	621.8	1,936.2
North & Central America	3,330.00	166.5	41.3	106.6	55.3	369.6
Oceania	244.6	12.2	3.0	7.8	3.6	26.7
South America	1,281.4	64.1	15.9	41.0	68.4	189.3
World Total	32,047.8	1,602.4	397.7	1,025.5	1,275.7	4,301.3
U.S.	2,721.3	136.1	33.8	87.1	77.1	334.0

Source: Food and Agricultural Organization of the United Nations and Guenthner, et al., 2001

Table 5: Present Value of the flow of future annual gross benefit attributed to the development and adoption of the genetically modified potato variety

Region	Present Value over 25 Years ($)	Annual Present Value ($)
Africa	1,225,298,079	49,011,923
Asia	10,001,285,145	400,051,406
Europe	12,196,068,234	487,842,729
North & Central America	2,341,246,832	93,649,873
Oceania	184,207,218	7,368,288
South America	1,207,055,399	84,696,438
World Total	27,073,917,142	1,082,956,685
U.S.	2,117,440,957	84,696,438

Table 6: Annual reduction in active toxic ingredients attributed to the development and adoption of the genetically modified potato

Region	Reduction in active toxic ingredients (kg)
Africa	1,339,965
Asia	10,276,144
Europe	25,604,958
North and Central America	2,275,268
Oceania	150,172
South America	1,507,767
World Total	41,154,274
U.S.	1,531,544