The Value of Corn and Soybean Neonicotinoid Seed Treatments for Canada

AgInfomatics

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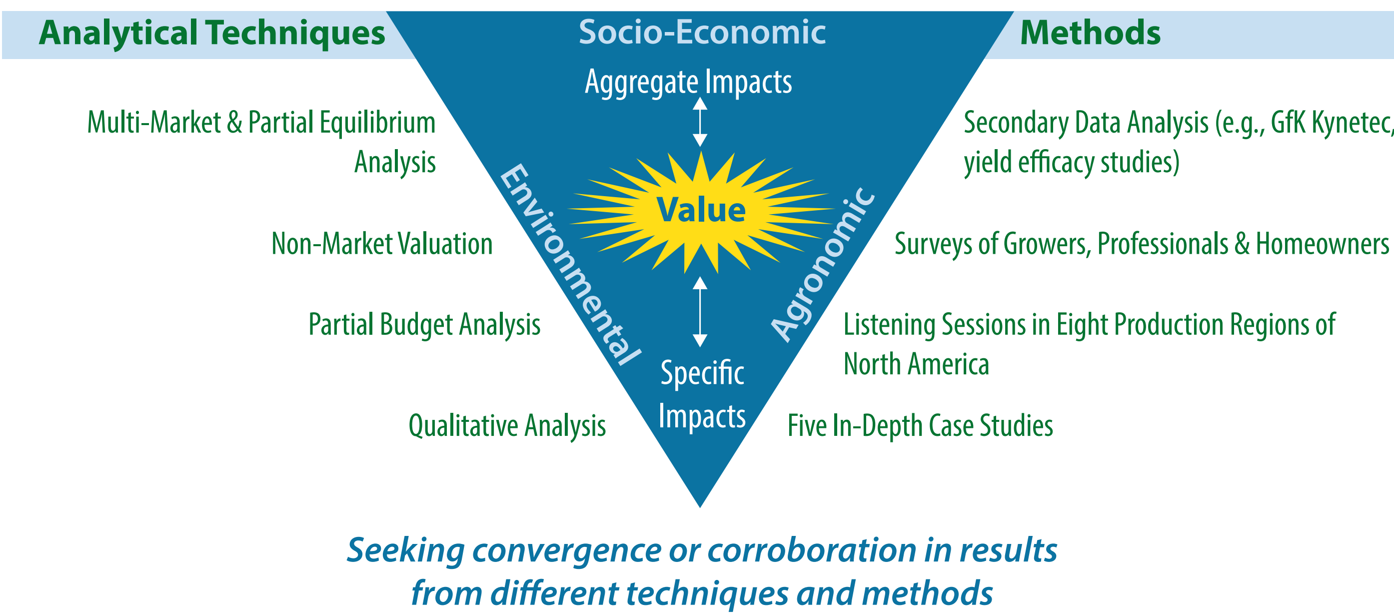
Contents

Introduction

AgInfomatics, a Limited Liability Corporation operating out of Madison, Wisconsin, U.S. as an independent agricultural research firm, prepared this report as part of a larger effort. AgInfomatics employed 14 PhD research scientists from a variety of agricultural disciplines to publish a series of 15 reports on the value of neonicotinoids in North American agriculture and the turf and ornamental industry. These reports have been made available to Health Canada's Pest Management Regulatory Agency (PMRA), the U.S. Environmental Protection Agency (EPA), the general public and are available at http://growingmatters.org/studies/. Several manuscripts are in preparation that will be submitted to peer-reviewed scientific journals based on the analysis in these reports.[1]

This document was prepared in response to the PMRA's draft assessment on the benefit of neonicotinoid seed treatments in corn and soybeans. The 15 AgInfomatics reports used several of methods and scales of analysis to develop a robust perspective on the benefits of neonicotinoid insecticides in North America using a data triangulation approach. This report distills some of the results from these reports, focusing on corn and soybeans grown in Canada, to compliment the PMRA draft assessment.

Figure 1. The analytical framework: A comprehensive effort behind the counterfactual analysis.



1 In addition to the Canadian-specific information summarized in this document, an equilibrium displacement model (Mitchell, 2015) was previously shared with the PMRA on the macroeconomic value of neonicotinoids corn and soybean seed treatments to the Canadian market. However, recently analysis of the data has suggested that the assumptions used in the Canadian macro-assessment may be incorrect due to the recent transition of Canada moving from a corn importer to a corn exporter, and influences from the U.S. market. Consequently, we recommend that the PMRA exclude the results reported by Mitchell (2015) at this time until a through reassessment is completed. Nevertheless, the data presented herein still illustrates multiple values of neonicotinoid seed treatments to the Canada corn and soybean grower.

AgInfomatics used counterfactual logic to guide the overall analysis on the value of neonicotinoids. This meant assuming that neonicotinoids are no longer available, and then estimating value as substitutions, alternatives and unanticipated impacts are identified and measured. The term counterfactual implies 'contrary to the facts.' By hypothetically removing neonicotinoids, their value becomes apparent by measuring these substitutions, alternatives and unanticipated impacts in the metrics of commercial agriculture (e.g., yield) and impacts related to human safety and the environment (Ferraro, 2009).

Counterfactual analyses are common in economic and political disciplines where it is necessary to assess the likely impacts of proposed policies and regulations. Cowan and Foray (2010) note that counterfactual condition statements are ubiquitous in any scientific endeavor and discuss the strengths and pitfalls of this approach. The counterfactual analysis developed by AgInfomatics asked the question, ***What would happen to North American agriculture if neonicotinoids were not available?***

Identifying value of neonicotinoids in North American agriculture required a sophisticated methodology. AgInfomatics selected a strategy of data triangulation to provide the most robust answer to the counterfactual question (Denzin and Lincoln, 2000). See Figure 1.

Data triangulation means using multiple methods to analyze the same phenomena. In this case, qualitative techniques were used to define the scope of the issues and to provide in-depth perspectives that are not possible with just statistical analyses or data summaries. Multiple quantitative techniques allowed development of specific measurements that could then be integrated with other results for further analysis or provide a stand-alone understanding of the value of specific attributes of neonicotinoids. According to Denzin (2012), "The combination of multiple methodological practices, empirical materials, perspectives and observers in a single study is best understood as a strategy that adds rigor, breadth complexity, richness and depth to any inquiry." Measuring the same phenomena using different methods enhances the validity of the results through eliminating bias and potential alternative explanations of the research question.

The comprehensive approach to develop an understanding of the value of neonicotinoids in Canadian corn and soybean production involved, directly or indirectly, the following methods and techniques:

Partial budget analysis. A partial budget analysis is the tabulation of expected gains and losses due to a relatively small change in overall farming method or production practices, such as a change in access to neonicotinoids.

Partial equilibrium analysis. The partial equilibrium analysis looks at the production processes that impact the price for one good or commodity, while holding other changes in the market constant. This assumption of holding all other factors constant (i.e., *ceteris paribus)* is the crux of partial equilibrium analysis.

Case studies. A case study is an in-depth descriptive analysis and investigation of a specific situation. The advantage is the richness and elaboration in gaining an understanding of the specific phenomena being studied, while the disadvantage is the time and costs it takes to produce this outcome. While a case study was not conducted with a Canadian grower, some of the insights garnered from the other case studies have salience to the Canadian situation.

Survey research. There are many types and degrees of sophistication in survey research. Commonalities include the selection of individuals from a larger population using a specific method, a set of standardized questions, statistical analysis and some level of generalization to the larger population. Survey research was used with growers in both the U.S. and Canada.

Secondary data analysis. Taking advantage of the wealth of information that already exists is a role of secondary data analysis. In this case, prior research such as product efficacy studies or market research can be the source of valuable information.

Additional information has been incorporated into this report based on our on-going research and our experiences summarizing and presenting these results to a variety of audiences over the last several months following the release of the original reports by AgInfomatics. We have presented summaries of this research at various academic conferences, to the U.S. EPA Biological and Economic Analysis Division (with PMRA personnel participating electronically via teleconferences) and to the USDA Office of Pest Management Policy. However, based on discussions during these presentations as well as our review of the PMRA's draft assessment, it seems apparent that some aspects of the original reports would benefit from additional clarification, some of which we provide here. This report covers four themes pertaining to the value of neonicotinoid insecticide seed treatments to Canadian corn and soybean growers.

First, this report updates and summarizes the Canadian corn and soybean results from the AgInfomatics report, *A Meta-Analysis Approach to Estimating the Yield Effects of Neonicotinoids* (Mitchell 2014), previously submitted to the PMRA. While that report assembled yield data from small plot field trials from multiple sources in an aggregate fashion, this document provides tables and figures containing updated data from the Canadian corn and soybean studies used in the yield meta-analysis to provide a local context for the information. In addition, this report summarizes yield data from three U.S. states (Michigan, New York, Wisconsin) that are similar to corn and soybean production in the major corn growing provinces of Ontario and Quebec in order to supplement the data from Canadian sources.

Second, this report discusses statistical significance, as used by academic researchers, to determine if a technology or practice has an effect and the concept of managerial significance, as used by farmers, to assess the value of new technologies or practices. Both statistical and managerial significance are important and have their places, but when considered independently, these methods can arrive at different conclusions as to the value of a practice or technology based on the same data. To illustrate the point, we have summarized the recently published Gaspar et al. (2015) paper and its implications as an application of managerial significance to the value

of neonicotinoid seed treatments compared to untreated control or fungicide-only seed treatments.

Third, the report summarizes key results from a telephone survey of 240 Canadian corn and soybean farmers. The collected data and analysis are described and summarized in the report *Value of Insect Pest Management to U.S. and Canadian Corn, Soybean and Canola Farmers* (Hurley and Mitchell 2014). Collected data includes their pests of concern, their pest management practices used and the relative importance of 20 different factors when they make their pest management decisions. These results help understand the motivations and sources of value that Canadian corn and soybean farmers derive from neonicotinoid seed treatments relative to their other options. As a part of this telephone survey, contingent valuation questions were asked and from farmer responses, dollar value measures of the value that farmers derive from neonicotinoid seed treatments and other pest management practices were estimated. These are comprehensive estimates of value, encompassing not only the monetary value of increased yield and lower cost, but also non-monetary values from benefits, such as improved human and environmental safety, reduced yield risk and convenience of use.

A summary of the major themes or issues that were heard during an all-day listening session with growers and agri-professionals is included as the fourth theme in this report. This session was held in London, Ontario on March 20th, 2014 with ten growers participating. Agriculture and Agri-Food Canada describes agriculture in Canada as "a modern, highly complex, integrated, internationally competitive and growing part of the Canadian economy." As is the case across North America, fewer larger and specialized farms continue to take advantage of technological innovation to lower per unit costs of production. Yet, at the same time, there is increasing knowledge about the human health and environmental impacts of modern agricultural production. Consequently, today's grower is challenged to remain competitive by searching out science-based production and marketing technologies, while also balancing traditional beliefs in stewardship and community responsibility. The listening session provided an authentic representation of this dynamic in Canadian agriculture. Equally important, statements made at the listening session corroborated key results that emerged in the quantitative analyses.

Theme 1: Canadian Corn and Soybean Yield Data Meta-Analysis

The first theme addresses the critical question of the yield response of using a neonicotinoid seed treatment. A meta-analysis approach was used to assemble data from multiple studies in order to estimate the yield effects of neonicotinoid seed treatment. The methodology and criteria used to determine which data were included in the yield meta-analysis are described on pages 2-3 of Mitchell (2014). The vast majority of the Canadian corn and soybean yield data are from the field research programs of Dr. Art Schaafsma and Dr. David Hooker, both at the University of Guelph's Ridgetown campus in Ontario. The data we found were from field studies conducted over several years at eight locations around Ontario but most commonly in the Ridgetown area (see Appendix Tables A1 and A2). The only exception is one site-year of corn yield data from British Columbia from a study published by Kabaluk and Ericsson (2007).

For data to be included, a study had to use replicated small plots and collect yield data from plots receiving neonicotinoid seed treatments as well as from untreated (i.e. control) plots or from plots receiving a conventional insecticide treatments (e.g. foliar or granular treatment). Care was taken to ensure that the only difference between neonicotinoid-treated plots and untreated control plots was from the use of a neonicotinoid seed treatment. For example, if the treatment combined a neonicotinoid and a fungicide (e.g., Cruiser Maxx® Beans), then the untreated control had to include a fungicide so that the only difference between the treated and untreated control plots was the use of the neonicotinoid insecticide. Within a site-year, if there were differences in the rates of neonicotinoid seed treatments applied, yields from the neonicotinoid seed treatments were averaged across the different rates. For example, if a site used two different application rates for imidacloprid (Gaucho®), yields for these two treatments were averaged. Also, if this site-year also evaluated thiamethoxam (Cruiser®) and clothianidin (Poncho®), yields for these treatments were calculated separately.

The data in Appendix Tables A1 and A2 are slightly different than the data included in the main report (Mitchell 2014). As part of the preparation of this report on the Canadian value of neonicotinoid corn and soybean seed treatments, the data were reexamined, and we noted that the paper of Kullik, Sears, and Schaafsma (2011) used some of the same corn data as Kullick, Schaafsma and Hooker (2003, 2004). Appendix Table A1 contains the corn yield data used for this analysis and summarizes these data in the figures and tables.

Also, upon re-examining the yield data in the Hooker et al. (2012) project completion report, we realized we could construct additional yield comparisons, more than previously reported in Mitchell (2014); thereby creating additional strength to the Canadian analysis. The original yield meta-analysis (Mitchell 2014) used the yields for the untreated control treatments and the neonicotinoid seed treatment. Appendix Table A2 in this report uses these two yields and matches them to the yields for the foliar application of lambda-cyhalothrin (Matador®). In addition, Appendix Table A2 also creates another triplet of yields: foliar fungicide (Quadris®) as a control, a neonicotinoid seed treatment plus the foliar fungicide as the neonicotinoid treatment, and the foliar application of a tank-mix of fungicide and an insecticide (Quadris® + Matador®) as an alternative insecticide. This process gives 16 observed triplets of control, neonicotinoid and alternative insecticide yields for each site year (as there are also two planting dates, two tillage and two fertilizer treatments). This approach uses the entire yield data collected with the exception of the treatments with a neonicotinoid seed treatment plus a foliar application of an insecticide or plus a foliar application of an insecticide-fungicide tank-mix (both of which were excluded from the analysis). This process not only adds more Canadian observations but also several observations of Canadian data comparing a neonicotinoid seed treatment to an alternative insecticide, which the original yield meta-analysis reported in Mitchell (2014) did not include.

It should be noted that the soybean data assembled for this analysis did not include the field-scale data from Hooker et al. (2012) chapter 6 (pp. 98 ff) for two reasons. First, the data were from larger field-scale trials, not small plot studies as were used for the other data. Second, the neonicotinoid seed treatment trials also included HiStick® inoculant, while the untreated control did not have the neonicotinoid seed treatment trials or the HiStick® inoculant, potentially confounding any yield effects observed for the treatment.

Appendix Tables A1 and A2 report all the data used for this summary for Canada. For corn, there are data from 25 site-years, plus the article from Kabaluk and Ericsson (2007) that reports yields averaging across three study sites. The final result is 71 paired observations of a control yield and a neonicotinoid seed treatment, plus 30 observations that also include yield for an alternative insecticide treatment. For soybean, there are data from 18 site-years, giving 120 paired observations for a control yield and a neonicotinoid seed treatment, plus 88 observations that also include yield for an alternative insecticide treatment. Note that similar to the main report (Mitchell 2014) the six-sigma rule was applied (i.e. any observation more than six standard deviations from the mean was dropped as an outlier). This rule removed one corn and one soybean observation from the data set, both comparing a neonicotinoid seed treatment to an untreated control, as the yield benefit was 200% and 430%, respectively. Thus, the final data for the control and neonicotinoid treated yield have 70 observations for corn and 119 for soybeans.

The yield benefit for a neonicotinoid treatment compared to an untreated control was calculated as follows:

$$\text{\% Yield Benefit} = \frac{(\text{Neonicotinoid Yield} - \text{Control Yield})}{\text{Control Yield}} \times 100 .$$

Similarly, the yield benefit for a neonicotinoid treatment compared to an alternative insecticide was calculated as follows:

$$\text{\% Yield Benefit} = \frac{(\text{Neonicotinoid Yield} - \text{Alternative Yield})}{\text{Alternative Yield}} \times 100 .$$

Canadian Yield Data Summary

Table 1 summarizes the yield benefit results for the Canadian corn data, while Table 2 does the same for the Canadian soybean data. All but one corn observation are from data collected in Ontario. Tables 1 and 2 also report comparable data from the Mitchell (2014) report for Michigan, New York and Wisconsin. The data in Tables 1 and 2 show that the corn and soybean yield benefits for neonicotinoid seed treatments in Canada are, in general, larger than in the U.S. states in the Great Lakes region near Ontario. Also, the standard deviations of the yield benefit for the Canadian data are noticeably larger than for the data from the selected U.S. states.

Table 1 shows that the yield benefit in corn for neonicotinoid seed treatments compared to untreated control treatments averages more than 11% for the Canadian data, which is comparable to the yield benefit in Wisconsin, a little larger than the benefit in Michigan and noticeably larger than the benefit in New York. However, we note that though there are 70 obser-

Table 1. Sample statistics for corn yield benefits for neonicotinoid treatments compared to untreated control and alternative insecticide treatments for Canada and key U.S. states

Neonicotinoid compared to	Nation or State	Number of Observations	Average	Standard Deviation	t statistic	p value
Untreated Control	Canada	70	11.07%	17.55%	5.280	<0.0001
	Michigan	6	9.31%	15.71%	1.451	0.1033
	New York	6	3.26%	5.02%	1.591	0.0863
	Wisconsin	29	11.93%	7.49%	8.569	<0.0001
Alternative Insecticide	Canada	30	9.81%	40.67%	1.321	0.0984
	Michigan	---	---	---	---	---
	New York	4	2.47%	4.03%	1.227	0.1537
	Wisconsin	25	-0.36%	4.49%	-0.401	0.3459

vations from Canada, there are only 6 observations each from Michigan and New York and 29 from Wisconsin. Table 2 in Mitchell (2014) reports that the pooled average yield benefit for all the U.S. corn yield data is 17.8% for 697 observations, so the Canadian yield benefit in Table 1 here is smaller than this average.

Table 1 here also shows that the yield benefit for neonicotinoid seed treatments compared to alternative insecticide treatments averages 9.8% in Canada, which is much larger than in Wisconsin and New York. Again, we note that there are 30 observations from Canada, none from Michigan, 4 from New York and 25 from Wisconsin. Table 3 in Mitchell (2014) reports that the pooled average yield benefit for all the U.S. corn yield data is 4% for 399 observations, so the Canadian yield benefit in Table 1 here is much larger than this average.

The soybean yield benefit data in Table 2 show similar trends. The average yield benefit for neonicotinoid seed treatments compared to untreated con-

Table 2. Sample statistics for soybean yield benefits for neonicotinoid treatments compared to untreated control and alternative insecticide treatments for Canada and key U.S. states

Neonicotinoid compared to	Nation or State	Number of Observations	Average	Standard Deviation	t statistic	p value
Untreated Control	Canada	119	8.48%	22.69%	4.078	<0.0001
	Michigan	19	3.04%	6.61%	2.007	0.0300
	New York	3	3.16%	0.79%	6.952	0.0100
	Wisconsin	97	3.22%	5.22%	6.074	<0.0001
Alternative Insecticide	Canada	88	1.56%	7.86%	1.861	0.0331
	Michigan	8	-8.33%	15.05%	-1.565	0.0808
	New York	---	---	---	---	---
	Wisconsin	24	-0.09%	4.79%	-0.090	0.4646

trol treatments in Canada is almost 8.5%, much larger than the average of a little more than 3% for Michigan, New York and Wisconsin. The standard deviation of this yield benefit for the Canadian data is also noticeably larger than for the data from these same U.S. states. Also, there are 119 observations from Canada, 97 from Wisconsin, 19 from Michigan and only 3 from New York. Table 2 in Mitchell (2014) reports that the pooled average yield benefit for all the U.S. soybean yield data is 2.8% for 642 observations, so the Canadian yield benefit in Table 2 here is much larger than this average.

Table 2 also shows that the yield benefit for neonicotinoid seed treatments compared to alternative insecticide treatments averages almost 1.6% in Canada for the 88 observations, which is larger than in Wisconsin (essentially 0% for 24 observations) and Michigan (negative 8% for 8 observations). Table 3 in Mitchell (2014) reports that the pooled average yield benefit for all the U.S. soybean yield data is 0.2% for 216 observations, so the Canadian yield benefit in Table 2 here is noticeably larger than this U.S. average.

In summary, the data in Tables 1 and 2 show that the corn and soybean yield benefits for the use of neonicotinoid seed treatments in Canada are generally higher and potentially more variable than in nearby U.S. states in the Great Lakes region. On average, over multiple years and locations, these data suggest that the benefit is positive: 11.1% and 9.8% for corn and 8.5% and 1.6% for soybean, depending on the comparison (i.e., compared to an untreated control or alternative insecticide application, such as a foliar spray). To give some sense of the variability in the Canadian data, Appendix Figures A1 through A8 provide graphical detail for the neonicotinoid yield benefits for corn and soybeans than the numbers in Tables 1 and 2. Notably, although the benefits are positive; on average, there is tremendous variability with wide ranges of yield benefits occurring for these small plots. This variability has implications for small plot research studies and for observed field performance of neonicotinoids.

Theme 2: Managerial Significance and Statistical Significance

An implication of the large variably in the neonicotinoid seed treatment yield benefit is that it is difficult to consistently identify yield benefits in individual small-plot studies without a employing an impractical number of replicates. As a result, one would expect that some studies find a statistically significant yield benefit from the use of neonicotinoid seed treatments relative to untreated control or alternative insecticides (Schaafsma et al. 2004b, Smith et al, 2008b), and that others do not (Schaafsma et al. 2000; Kullick et al. 2003; Smith et al. 2008a). With the relatively large variability in the neonicotinoid seed treatment yield benefits, as indicated by Tables 1 and 2 and Appendix Figures A1 to A8, finding statistical significance may be difficult.

Meta-analysis is a statistical method that assembles data from multiple studies to potentially identify treatment effects, while simultaneously considering the inherent variability of the data. The data in Appendix Tables A1 and A2 and the summaries in Tables 1 and 2 are a basic meta-analysis, simply calculating the means and standard deviations of the assembled data. In this case, the goal is to determine the average neonicotinoid treatment effect over as many studies that meet the selection criteria to be included in the data.

A field can be thought of as combination of multiple small plots; therefore across fields and over multiple locations and years, a variety of outcomes will occur. As previously mentioned, over years and locations, the data summarized in Tables 1 and 2 suggest that, on average, the neonicotinoid yield benefit is positive: 11.1% or 9.8% for corn and 8.5% or 1.6% for soybeans, depending on the comparison to untreated controls or to an alternative method of pest control. For individual plots in any given year, these benefits may not be realized or statistically significant due to the relatively large amount of variably, but on average, over years and fields, these benefits become evident.

Traditionally, a 5% level of significance is used to balance between type I errors (i.e. 'false positives') and type II errors (i.e. 'false negatives') in research. This level implies that if a study were repeated, 95% of the time, the treatment effect would be identified again, so that a researcher can be fairly certain that the observed treatment effect is 'real'. Farmers, however, do not require this level of certainty, as they are willing to use treatments that provide benefits with less than 95% certainty. Indeed, decision makers in many situations also do not need this level of certainty.

A practice or treatment may be 'managerially significant' in the sense that most farmers would be willing to use the practice or treatment, even though small plot research studies may find that the practice does not have a statistically significant effect at the 5% level on yield or net returns. To be managerially significant, the combination of the likelihood and the size of the benefit must create enough value to compensate for the cost so that a farmer would adopt the practice. Neonicotinoid seed treatments would seem to fall into this category for many Canadian corn and soybean farmers. The yield benefits indicated in Tables 1 and 2 combined with crop prices and average yields imply that, on average for many farmers, the treatments would generally pay for themselves relative to the alternative (i.e. no treatment or an alternative insecticide, such as a foliar application), particularly once combined with the other benefits that neonicotinoid seed treatments provide.

Farmers commonly face managerial questions of this sort — choosing a practice to use with uncertainty regarding the need for and net benefit of the different options. Two tools commonly used to examine the decision are partial budget analysis and break-even probability. We first present an example partial budget analysis.

Example Partial Budget Analysis

A partial budget analysis (Tigner 2006) ignores the uncertainty in costs and/or benefits and simply examines average gains and costs. The focus is on the costs and benefits that change between the decision options. To illustrate, we present an example based on the lowest yield benefit case in Tables 1 and 2 for Canada, the 1.6% average yield benefit for soybean for a neonicotinoid seed treatment compared to an insecticide alternative.

Farmer profit ($/ha) with a neonicotinoid seed treatment is

Farmer profit ($/ha) with a neonicotinoid seed treatment is

$$\text{Profit} = \text{Price} \times \text{Yield} \times (1 + \text{Yield Benefit}) - \text{Seed Treatment Cost} - \text{All Other Costs}, \quad (1)$$

where Price is the soybean price ($/ton), Yield is expected soybean yield (ton/ha) with a foliar-applied insecticide, Yield Benefit is the yield benefit (%) for the neonicotinoid seed treatment relative to an alternative insecticide (i.e., 1.6% from Table 2), Seed Treatment Cost is the cost ($/ha) for the seed treatment, and All Other Costs ($/ha) includes all the other costs of production.

Farmer profit ($/ha) with an alternative, foliar-applied insecticide is

$$\text{Profit} = \text{Price} \times \text{Yield} \times (1 + \text{Yield Benefit}) - \text{Seed Treatment Cost} - \text{All Other Costs}, \quad (2)$$

where Price is the soybean price ($/ton), Yield is expected soybean yield (ton/ha) with a foliar-applied insecticide, Scouting Cost is the cost ($/ha) for insect pest scouting, All Insecticide Costs ($/ha) includes both the cost of foliar application and for the insecticide active ingredient, α is the proportion of acres treated and All Other Costs ($/ha) includes all the other costs of production. The assumption is that all of the planted area is scouted, but only α% is treated with a foliar-applied insecticide.

Based on these equations, the net gain for a farmer is profit with a seed treatment minus profit with a foliar-applied insecticide, or equation (1) minus equation (2). After simplification this net gain is:

$$\text{Net Gain} = \text{Price} \times \text{Yield} \times \text{Yield Benefit} - \text{Seed Treatment Cost} + \text{Scouting Cost} + \alpha \text{All Insecticide Costs}. \quad (3)$$

Equation (3) shows that the net gain ($/ha) for a neonicotinoid seed treatment relative to a foliar-applied insecticide would be the net revenue gain for using the seed treatment plus the costs for scouting and applying the foliar insecticide when needed. These costs are added in equation (3) because these costs are avoided when switching from using scouting and foliar-applied insecticides to using a neonicotinoid seed treatment. If the base case for comparison was untreated seed, the scouting and insecticide costs would not be added in equation (3), but the yield benefit would be much larger (i.e., 8.5% for soybean in Table 2).

Based on rough Ontario averages for 2013 of $520/ton for the soybean price and 3 tons/ha for yield (PMRA 2015, p. 21, note 5), a yield benefit of 1.6% implies a revenue gain of $24.96/ha. Using OMAFRA 2015 Crop Budgets for soybean (OMAFRA 2015, p. 13), the cost of a neonicotinoid seed treatment is $25/ha. Based on U.S. data for the few northern states with data (Iowa and Michigan), we use $12.50/ha as the cost of insect scouting (Mitchell 2014b, p. 26). Based on U.S. insecticide costs and OMAFRA 2015 Crop Budgets, we use a cost of $11/ha for the alternative insecticide (lambda-cyhalothrin) and $25/ha for the cost of application (Mitchell 2014b, p. 56; OMAFRA 2015, p. 13). Finally, based on the survey of Canadian soybean farmers (Hurley and Mitchell 2014, p. 21), we use the adoption rate for neonicotinoid seed treatments (66.2% of seeded area) as an estimate of the proportion of the soybean area that would be treated. Based on these assumptions, the value of the neonicotinoid seed treatment relative to a foliar applied non-neonicotinoid alternative would be 520 x 3 x 1.6% – 25 + 66.2% x (11 + 25) = $36.29/ha ($14.69/acre). This value is comparable to the value of $15.79/A for neonicotinoid seed treatments for Canadian soybean farmers estimated by Hurley and Mitchell (2014, p. 40) using non-market valuation techniques on data from a farmer survey.[2]

This partial budget estimate will, of course, vary depending on the price, yield, cost and benefit assumptions — all of which vary and many of which will be uncertain at the time the farmer must decide. One way to analyze this decision in order to understand farmer choices and provide guidance is to estimate the break-even probability, which is the probability that the value of the yield increase from using the practice or treatment will be at least large enough to pay the cost of the practice or treatment. In other words, the break-even probability is the probability that the farmer will break even or make money if the practice is used. Mitchell and Hutchison (2008) discuss and illustrate the break-even probability broadly in the context of risk management in Integrated Pest Management (IPM), while Esker and Conley (2012) use it to examine the value of fungicide seed treatments for soybeans in Wisconsin. However, Gaspar et al. (2015) recently combined break-even probabilities and profit maximization to examine optimal seeding density with and without neonicotinoid seed treatments for soybeans in Wisconsin, which has a substantial impact on the grower cost/benefit analysis.

An Application of Managerial Significance and Statistical Significance

Gaspar et al. (2015) conducted replicated soybean field trials at nine locations over two years in Wisconsin. The trials used a randomized complete block design with four replications of three seed treatments (i.e., untreated control, fungicide only (Apron Maxx® RFC), and neonicotinoid insecticide plus fungicide (Cruiser Maxx®) and six seeding rates (98,800, 148,200, 197,600, 247,000, 296,400 and 345,800 seeds per ha), with yield data collected for each plot. Nonlinear least squares was used to estimate a negative exponential model for the response of harvested soybean yield to the seeding rate for each seed treatment. The specific model was:

$$\text{Yield} = Y_{\max}(1 - \exp(-\beta \times \text{Seeding Rate})), \quad (4)$$

where Y_{max} and β are estimated parameters for each seed treatment and Yield and Seeding Rate are respectively, the observed yield (kg/ha) and experimentally controlled seeding rate (1,000 seeds per ha). The parameter Y_{max} is the asymptotic yield maximum (kg/ha) and β defines the responsiveness of yield as seeding rate increases for each seed treatment. Estimated parameters were Y_{max} = 4,184 and β = 0.015 for the untreated control, Y_{max} = 4,213 and β = 0.014 for the fungicide only (Apron Maxx®) seed treatment, and Y_{max} = 4,329 and β = 0.017 for the neonicotinoid plus fungicide (Cruiser Maxx®) seed treatment (Gaspar et al. 2015, Table 2).

2 Hurley and Mitchell (p. 40) report an estimated value of US$14.53/A, which is $15.79/A when converted to Canadian dollars using the 0.92 conversion factor they report as prevalent at the time of the survey.

Based on these yield response functions, the economically optimal seeding rate was determined by maximizing the partial profit[3]

$$\text{Partial Profit} = \text{Soybean Price} \times Y_{\max}(1 - \exp(-\beta \times \text{Seeding Rate})) - \text{Seed Price} \times \text{Seeding Rate},$$

where Soybean Price is the soybean price ($/kg) and Seed Price is the seed cost ($ per 1,000 seeds). The economically optimal seeding rate is found by setting the first derivative of partial profit with respect to the seeding rate equal to zero and solving for the seeding rate. This solution is

$$\text{Optimal Seeding Rate} = -\ln\left(\frac{\text{Seed Price}}{\beta \times Y_{\max} \times \text{Soybean Price}}\right) / \beta \qquad (5)$$

Equation (5) shows that not only does the optimal seeding rate depend on the variety, its agronomic potential and responsiveness to plant density (Y_{max} and β) but also on the soybean price and the cost of the seed with the seed treatments. As expected, the optimal seeding rate increases with the soybean crop price and decreases as the soybean seed cost increases. Once a seeding rate is set, it can be substituted into the yield equation (4) to calculate the associated yield.

Table 3 uses the optimal seeding rate equation (5) and the yield equation (4) to calculate the economically optimal seeding rate (1,000 seeds/ha) and the yield (kg/ha) for a range of soybean prices ($/mt) based on the parameter estimates for each seed treatment. The seed prices used were $0.36/1,000 seeds for the untreated control, $0.39/1,000 seeds for the fungicide only seed treatment (Apron Maxx®) and $0.44/1,000 seeds for the fungicide plus neonicotinoid seed treatment (Cruiser Maxx®), corresponding to prices of US$50/unit of 140,000 seeds for the untreated control, US$5/unit more for the fungicide only seed treatment (Apron Maxx®), and US$12/unit more for the fungicide plus neonicotinoid seed treatment (Cruiser Maxx®).

Figure 2 plots the yield response curves for the three seed treatments and illustrates the optimal seeding rate and expected yield for the untreated control (or Apron Maxx®) as point A and the neonicotinoid seed treatment with a fungicide (Cruiser Maxx®) as point B for the case with soybean price of $440/ton. Figure 2 shows the two effects that occur as a result of adopting the neonicotinoid seed treatment relative to the untreated control or the fungicide-only seed treatment (moving from point A to point B):

1) the optimal seeding rate decreases, and

2) the associated yield increases.

These changes occur because the estimated Y_{max} and β parameters differ among the treatments; however, because the estimated parameters for the fungicide treatment and untreated control are similar in magnitude, the yield response curves are fairly similar so that the optimal seeding rates and associated yields are fairly similar (Figure 2).

3 Partial profit does not include costs and yield impacts for factors that do not change between the three seed treatments.

Figure 2. Soybean yield response to seeding rate for untreated control, Apron Maxx® (fungicide) and Cruiser Maxx® (neonicotinoid and fungicide) seed treatments and impact of switching from untreated control (point A) to a Cruiser Maxx® (point B) on the optimal seeding rate and yield

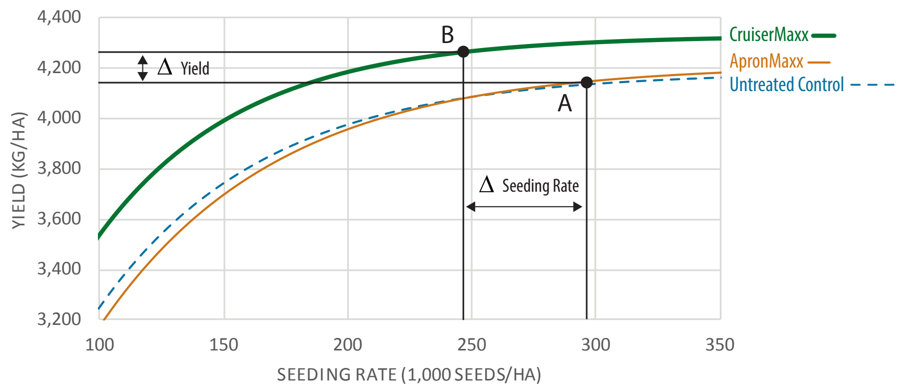


Table 3. Optimal seeding rates and associated yields for untreated control, Apron Maxx® (fungicide only) and Cruiser Maxx® (neonicotinoid and fungicide) seed treatments and the percentage difference in seeding rates and yields for Apron Maxx® and Cruiser Maxx® compared to the untreated control

Soybean Price = $330/mt

Treatment	Optimal Seeding Rate (1,000 seeds/ha)	Yield (kg/ha)	% Difference Compared to Untreated Control: Seeding Rate	% Difference Compared to Untreated Control: Yield
Untreated Control	276	4,117	----	----
Apron Maxx®	275	4,123	-0.4%	0.1%
Cruiser Maxx®	232	4,245	-15.9%	3.1%

Soybean Price = $440/mt

Treatment	Optimal Seeding Rate (1,000 seeds/ha)	Yield (kg/ha)	% Difference Compared to Untreated Control: Seeding Rate	% Difference Compared to Untreated Control: Yield
Untreated Control	295	4,134	----	----
Apron Maxx®	295	4,145	0.0%	0.3%
Cruiser Maxx®	249	4,266	-15.6%	3.2%

Soybean Price = $550/mt

Treatment	Optimal Seeding Rate (1,000 seeds/ha)	Yield (kg/ha)	% Difference Compared to Untreated Control: Seeding Rate	% Difference Compared to Untreated Control: Yield
Untreated Control	310	4,144	----	----
Apron Maxx®	310	4,158	0.0%	0.3%
Cruiser Maxx®	261	4,278	-15.8%	3.2%

Source: Gaspar et al. (2015)

Table 3 also reports the implied percentage changes in the optimal seeding rate and associated yield that occur relative to the untreated control for both fungicide and fungicide plus neonicotinoid insecticide seed treatments. Table 3 shows that across the range of soybean prices examined, the optimal seeding rates and associated yields are essentially the same for the untreated control and fungicide seed treatment (Apron Maxx®). However, for the neonicotinoid treatment (Cruiser Maxx®) compared to the untreated control (and essentially to Apron Maxx® as well), the optimal seeding rate decreased almost 16% and the optimal yield increased 3.1-3.2% across the range of soybean prices. This yield increase of slightly more than 3% for the neonicotinoid seed treatment relative to the untreated control or to the fungicide only seed treatment is consistent with the 3.22% yield benefit in Table 2 here reported for the 97 Wisconsin observations of a neonicotinoid seed treatment compared to an untreated control for the yield meta-analysis. The data reported and used by Gaspar et al. (2015) were not included in the data summarized in Table 2, and so provide additional evidence that in Wisconsin, a neonicotinoid seed treatment on average provides a little more than a 3% yield benefit for soybeans.

Gaspar et al. (2015) also examined the uncertainty of the yield benefit from the neonicotinoid seed treatment and estimated the break-even probability. More specifically, a Monte Carlo model of the partial profit for each seed treatment that draws the Y_{max} and β parameters from a multivariate normal distribution with means equal to the reported parameter estimates and variances and covariance as determined by the parameter standard errors and covariances. The final output from this Monte Carlo process is an empirical distribution of partial profit for each seed treatment that varies with the seeding rate. Monte Carlo integration implies that the average of these partial profits is the Monte Carlo estimate of expected partial profit and the proportion of these partial profits that is positive is the Monte Carlo estimate of the break-even probability. To normalize the results, Gaspar et al. (2015) report partial profit results as the increase over the base case of the untreated control at a seeding rate of 345,800 seeds/ha (140,000 seeds per acre), and the break-even probability as the probability that the seed treatment generates partial profit that equals or exceeds the same base case. Table 4 reports results from Gaspar et al. (2015) over the three soybean prices assumptions but only for the cases when the seeding rate equals its optimum level as reported in Table 3.

The results for the untreated control in Table 4 show that returns on average would increase $2/ha to $8/ha by reducing the seeding rate from 345,800 seeds/ha to the economically optimal level (276,000 to 310,000 seeds/ha as reported in Table 3). Furthermore, the break-even probabilities imply that a farmer making this seeding rate reduction would at least break even 69%-84% of the time. Compared to this same base case, the Apron Maxx® seed treatment at its economically optimal seeding rates would increase average returns by only $3/ha to $5/ha, and generate profits equal to or exceeding the base case only 51%-54% of the time. These cases suggest that, at least for these data from Wisconsin, there are some small profit gains to be had by moving to economically optimal seeding rates, but the fungicide-only seed treatment would be too risky to most farmers.

Table 4. Profit increases and break-even probabilities for untreated control, Apron Maxx® (fungicide only) and Cruiser Maxx® (neonicotinoid and fungicide) seed treatments relative to the base case of untreated control at 345,800 seeds/ha

	Profit Increase ($/ha)			Break-Even Probability		
	------- Soybean Price -------			------- Soybean Price -------		
Treatment	$330/mt	$440/mt	$550/mt	$330/mt	$440/mt	$550/mt
Untreated Control	8	4	2	0.84	0.76	0.69
Apron Maxx®	5	3	3	0.54	0.52	0.51
Cruiser Maxx®	50	61	74	0.89	0.87	0.86

Source: Gaspar et al. (2015)

The results in Table 4 also show that the Cruiser Maxx® seed treatment (neonicotinoid plus fungicide) at the economically optimal seeding rates in Table 3 would increase average profit by $50 to $74/ha compared to the base case of the untreated control at 345,800 seeds/ha. Furthermore, the break-even probabilities imply that a farmer using Cruiser Maxx® at these seeding rates would generate profits equaling or exceeding the base case 86%-89% of the time. These cases from Wisconsin suggest that there are not only some substantial gains to be made by using Cruiser Maxx® at economically optimal seeding rates, but that these gains are fairly certain.

Finally, note that the break-even probabilities in Table 4 imply that none of the expected profit increases are statistically significant. Specifically, the null hypothesis is that the increase in expected profits for the Cruiser Maxx® compared to the base case is zero. The break-even probabilities imply p values for this null hypothesis range from 100% – 89% = 11% to 100% – 86% = 14% depending on the soybean price. Since these all exceed 5%, the null hypothesis cannot be rejected; there is more than a 5% probability that the profit increase with the seed treatment would be negative. Despite this lack of statistical significance, these results are managerially significant; many farmers would be willing to use a practice that, on average, increased their returns by $50-$74/ha, with a probability of 86% -89% that their profit would increase.

How these results apply to Canada is unclear; as far as we know, no Canadian studies comparable to Gaspar et al. (2015) have been conducted. In an interim report, Bohner and Earl (2009) summarize two years of data from a three year study that used three seeding rates and varied use of neonicotinoid seed treatments as well as planting methods and spacing. Plant stand increased with a neonicotinoid seed treatment relative to untreated control, indicating that reduced seeding rates when using these seed treatments may allow growers to save input costs, but no statistically significant yield increase was found.

Furthermore, the average yield benefit in Table 2 for a neonicotinoid seed treatment relative to an untreated control for soybeans in Wisconsin is 3.22%, similar to the 3.1% to 3.2% in Table 3 for Gaspar et al. (2015). The average yield benefit in Table 2 for a neonicotinoid seed treatment relative to an untreated control for soybeans in Canada is 8.5%. This larger average

benefit suggests that, if the study and analysis were conducted in Ontario, the gap between the response curves for the untreated control and a neonicotinoid seed treatment would be larger than in Figure 2, and the yield increase larger than in Table 3. However, the Gaspar et al. (2015) study did not include a comparison to scouting-based application of foliar insecticides. The Hooker et al. (2012) report summarized field studies that did not vary seeding rates but did compare a neonicotinoid seed treatment to foliar applied insecticides. The implied yield benefit from these three years of data from Ontario are those summarized in Table 2 for the neonicotinoid treatment compared to an alternative insecticide, indicating a 1.6% average yield benefit. As the partial budget analysis above found, even this yield benefit is enough to imply more than $36/ha profit increase, but no break-even probabilities have been estimated.

Theme 3: Value of Neonicotinoids for Canadian Corn and Soybean Farmers

Economists have developed a variety of methods to estimate value of things that would seem difficult to estimate. A recent monograph, *Valuing Ecosystem Services: Toward Better Environmental Decision-Making*, commissioned by the U.S. National Academy of Sciences (U.S. NAS 2004), describes and summarizes these various methods as well as their importance in making regulatory decisions in the context of aquatic systems. Similarly, the U.S. EPA in its *Guidelines for Preparing Economic Analyses* (U.S. EPA 2010) puts these and even more valuation techniques into a regulatory context as method for estimating value as part of a cost-benefit analysis.

As part of a data triangulation methodology, AgInfomatics chose a contingent valuation method to estimate the total value of neonicotinoid seed treatments in the U.S. and Canada that will be discussed here. Contingent valuation is a common technique to measure the value of non-market goods and services. Specifically, the *Value of Insect Pest Management to U.S. and Canadian Corn, Soybean and Canola Farmers* (Hurley and Mitchell 2014) used an indirect, stated preference, contingent valuation approach to estimate the value of different pest management practices to U.S. and Canadian farmers (U.S. NAS 2004, p. 101).

Hurley and Mitchell (2014) used this approach to estimate the value of insect pest management to U.S. and Canadian corn, soybean and canola farmers. A survey of more than 1,700 farmers (740 in Canada) served as the primary data for their analysis, with the final results including an estimate of the net value farmers derive from the use of common pest management practices, including neonicotinoid seed treatments. This section summarizes the Canadian results from this larger analysis.

Farmer Survey for Contingent Valuation of Neonicotinoid Benefits for Farmers

The primary data for the non-market valuation of neonicotinoid seed treatments to U.S. and Canadian corn, soybean and canola farmers was a telephone survey of 1,700 farmers conducted by Market Probe, a professional market research firm with offices in the U.S. and Canada (http://www.

marketprobe.com/). A total of 622 corn farmers from twelve U.S. states and three Canadian provinces, 621 soybean farmers from fourteen U.S. states and three Canadian provinces, and 500 canola farmers from three Canadian provinces were surveyed. Focusing on the Canadian data, there were 121 corn farmers surveyed (30 from Manitoba, 60 from Ontario and 31 from Quebec) and 122 soybean farmers surveyed (32 from Manitoba, 60 from Ontario and 30 from Quebec). For the Canadian canola growers, 260 were from Saskatchewan, 158 from Alberta and 82 from Manitoba. The telephone surveys were conducted in February and March of 2014 for U.S. farmers and April/May of 2014 for Canadian farmers. U.S. farmers received U.S. $10 for their participation, Canadian canola respondents received Canadian $10, and Canadian corn and soybean respondents received Canadian $15.

The survey instruments were designed by the authors in consultation with Market Probe and technical experts at Bayer, Syngenta and Valent. First, participants were screened to ensure they had planted at least a minimal amount of the targeted crop (corn, soybean or canola) in 2013 and were not a chemical or seed company employee.[4] For the 2013 growing season, the survey then asked for information on the farmer's:

- operation (e.g., target crop acres, total crop acres, other crops planted, tillage practices, amount of leased land and presence of a livestock operation,
- actively managed insect pests, including the most important of these pests,
- use of alternative pest management practices (e.g., Bt corn, insecticidal seed treatments, soil insecticides and foliar insecticides), including specific products and number of acres treated,
- average production costs, yields and price received for any 2013 crop sold,
- source of insect pest management advice,
- most important concerns when making insect pest management decisions,
- perceived value of alternative insect pest management practices,
- biggest insect pest management concerns in the targeted crop, and
- education and farming experience.

The survey content was adjusted to fit the target crop (i.e., no Bt corn questions on the soybean survey) and modified to fit the Canadian context by using appropriate product names, units of measure and translating the survey into French for farmers in Quebec. Hurley and Mitchell (2014) includes in the appendices full (English) scripts of the telephone survey for each crop.

The full report (Hurley and Mitchell 2014) discusses and describes the data and results for the U.S. and Canadian canola farmers. However, in this report, we focus on the Canadian corn and soybean data and results from Canada. Tables 6, 7, and 8 in Hurley and Mitchell (2014) also summarize some of the characteristics of the surveyed U.S. and Canadian farmers and are not repeated here; but we believe these tables indicate that the survey

4 For U.S. corn and soybean farmers the minimal amount was 250 acres. For Canadian corn, soybean, and canola farmers, the minimal amount was 100, 60, and 250 acres.

Table 5. Pests actively managed and reported as most important to manage by Canadian corn and soybean farmers (% of respondents)

	-------------- Corn -------------			----------- Soybean ----------	
Pest	Actively Manage	Most Important	**Pest**	Actively Manage	Most Important
Corn borer	60%	54%	Aphid	43%	50%
Corn rootworm	31%	22%	Mite	7%	1%
Black cutworm	7%	3%	Beetle	5%	0%
Wireworm	6%	1%	Grasshopper	4%	5%
Armyworm	2%	0%	Wireworm	3%	0%
Grub	2%	0%	Nematode	3%	1%
Maggot	2%	0%	Slug	2%	0%
Cutworm	2%	0%	Grub	1%	0%
Aphid	1%	0%	Japanese Beetle	1%	0%
Flea Beetle	1%	0%	Maggot	1%	1%
Nematode	1%	0%	Cutworm	1%	1%
			Leafhopper	1%	0%

Source: Hurley and Mitchell (2014), p. 17-18.

farmer sample was representative of commercial farmers for these crops. Our summary focuses on the pests of concern, pest management practices used, how important various considerations are when making pest management decisions and finally, the estimated value of each of these different pest management practices to Canadian corn and soybean farmers.

Target Pests, Pest Management Practices and Pest Management Concerns

Table 5 reports the pests that Canadian corn and soybean farmers reported as those that they actively manage and those that are the most important pests. In general, the major corn pests are corn borers and corn rootworm, with black cutworm and wireworm the most important minor pests as well as several other minor pests mentioned, many of them soil dwelling (grubs, maggot) or early season above-ground pests (cutworm, flea beetle). Neonicotinoid seed treatments are useful for control of corn rootworm under low to moderate population pressure and are combined commercially with rootworm Bt corn to control other soil dwelling pests, such as wireworm grubs and maggots.

For soybeans, soybean aphid is the major pest, with mites and beetles as the most important minor pests, and again several other minor pests are mentioned, both soil dwelling and some early-season above ground pests. Soybean aphid can be managed with neonicotinoid seed treatments and/or foliar applications of neonicotinoids, plus neonicotinoid seed treatments can be used to control soil dwelling pests, such as wireworm, grubs and maggots.

Table 6 reports the pest management practices used by Canadian corn and soybean farmers, both as the percentage of survey respondents using each

Table 6. Pest management practices used by Canadian corn and soybean farmers

	-------------- Corn ------------		---------- Soybean ----------	
Practice	% Farmers	% Acres	% Farmers	% Acres
Neonicotinoid Seed Treatment	79%	75%	74%	66%
Foliar Insecticide	12%	5%	14%	7%
Bt Corn	90%	76%		
Soil Insecticide	3%	3%		

Source: Hurley and Mitchell (2014), p. 20-21.

practice and as the percentage of acres using these practices. Bt corn and neonicotinoid seed treatments are by far the most popular practices used, with 90% of farmers using Bt corn on 76% of seeded acres, while neonicotinoid seed treatments used by 79% of farmers on 75% of seeded acres. These products control corn borer and/or corn rootworm as well as most of the soil dwelling pests and early season pests listed in Table 5. Foliar insecticides are used only on 5% of corn seeded area and soil insecticides on only 3% of corn seeded area, showing that in general, these are not the preferred methods of insect management.

For soybeans, Table 6 shows that neonicotinoid seed treatments are by far the major method of insect control, used by 74% of the farmers on 66% of seeded acres. Again, foliar insecticides are not popular, used on only 7% of soybean seeded area. No Bt traits are available for soybean, and no soil insecticides are registered for use in soybeans in Canada.

Tables 5 and 6 show that Canadian corn and soybean farmers rely predominantly on seed-based methods for insect management, either as Bt corn or neonicotinoid seed treatments. The primary pests are soil dwelling pests like wireworm, seed maggots and different types of grubs or early season pests, such as cutworms and flea beetles. Foliar insecticide applications and soil applied insecticides are used on relatively few acres, likely as rescue treatments or for pests not controlled by the seed-based methods. Corn farmers have soil insecticide alternatives available to manage soil dwelling pests but use these proactively (i.e. at time of planting) on relatively few acres.

By comparison, Canadian soybean farmers have no soil insecticide alternatives available to manage soil dwelling pests other than neonicotinoid seed treatments, despite the fact that many farmers report actively managing a variety of such pests. Neonicotinoid seed treatments provide some control or early-season suppression of soybean aphid, but this pest can be also managed with foliar-applied insecticides. However, the data in Table 6 show that farmers clearly prefer to use seed treatments rather than foliar-applied insecticides to manage this pest — the most important soybean insect pest for half of the respondents.

Given these results, the data in Table 7 are not surprising. Farmers were asked, ***If you were able to buy the same seed without an insecticidal seed treatment, would you have still planted seed with an insecticidal seed treat-***

ment? Among both corn and soybean farmers responding to the survey, 66% said they would continue to do so, while only 22% said they would not. This information suggests that Canadian corn and soybean farmers overall strongly prefer to use seed-based methods of insect control like neonicotinoid seed treatments and/or Bt corn. Statements made by growers in the listening session and reported in this next section of this report support this interpretation.

The results summarized in Table 8 provide further evidence as to why farmers prefer seed-based pest management practices like Bt corn and neonicotinoid seed treatments, rather than foliar-applied and soil applied insecticides. Farmers were asked about the importance of 20 different considerations when making choices as to how to control insects with a particular insecticide. Based on Table 8, human and environmental safety factors, such as family and worker safety, protecting water quality and public safety, are the most important factors Canadian corn and soybean farmers consider. Crop protection and agronomic factors are also important, such as protecting yield, improving plant health and stand, and consistent insect control are also important, but secondary. Protecting beneficial insects and wildlife as well as economic factors, such as cost and crop marketability are also important, while various convenience and time saving considerations are of minor importance relative to human and environmental safety, and crop protection and agronomics.

Overall the results in Table 6 and 8 suggest that Canadian corn and soybean farmers see Bt corn and neonicotinoid seed treatments as an important part of 'modern' pest management that is safer for people and the environment and provides effective crop protection. Foliar-applied insecticides are options for both crops and soil insecticides for corn, but Table 6 shows that for the pests they manage, Canadian corn and soybean farmers strongly prefer to use seed-based control methods. Finally, the results in Table 8 also indicate that Canadian corn and soybean farmers treat human and environmental safety as their primary concern when making pest management choices, even more important than crop protection. These results suggest that Canadian farmers are tremendous allies in the appropriate use of insecticides for the public good, and their concerns can be used to achieve publicly desirable outcomes by working with farmers.

Table 7. Canadian farmer responses to the question *"If you were able to buy the same seed without an insecticidal seed treatment, would you have still planted seed with an insecticidal seed treatment?"* (% of respondents that answered)

Response	Corn	Soybean
Yes	66%	66%
No	22%	22%
Some, Not All	8%	6%
Don't Know	5%	7%

Source: Hurley and Mitchell (2014), p. 106.

Table 8. Percentage of Canadian corn and soybean farmers answering important or very important for the following considerations when asked, *When choosing how to control insects with a particular insecticide, how important are each of the following?* (Type 1 (green) denotes human and environmental safety factors, type 2 (yellow) denotes crop protection and agronomic factors, type 3 (orange) denotes economic factors, and type 4 (blue) denotes time savings factors.)

Consideration	Type	Corn	Consideration	Type	Soybean
Family & worker safety	1	98%	Family & worker safety	1	100%
Protecting water quality	1	96%	Protecting yield	2	98%
Public safety	1	95%	Public safety	1	93%
Protecting yield	2	95%	Protecting water quality	1	91%
Improving plant health	2	94%	Cost	3	88%
Improving crop stand	2	93%	Improving plant health	2	88%
Consistent insect control	2	92%	Consistent insect control	2	87%
Protecting beneficial insects	1	91%	Crop marketability	3	86%
Crop marketability	3	85%	Improving crop stand	2	86%
Protecting wildlife	1	83%	Protecting beneficial insects	1	85%
Saving time and labor	4	83%	Protecting wildlife	1	84%
Long-lasting insect control	2	82%	Long-lasting insect control	2	82%
Cost	3	80%	Ability to plant early	2	79%
Ability to plant early	2	78%	Flexibility	4	76%
Flexibility	4	76%	Saving time and labor	4	76%
Simplicity	4	75%	Convenience	4	72%
Replant/product guarantees	3	71%	Reducing equipment wear	3	66%
Convenience	4	68%	Simplicity	4	65%
Reducing equipment wear	3	64%	Replant/product guarantees	3	65%
Reducing scouting	4	50%	Reducing scouting	4	51%

Source: Summarization of data collected by Hurley and Mitchell (2014).

Estimated Farmer Value of Pest Management Practices

The survey included a question that asked those farmers using a pest management practice to indicate the additional value they derived from using that practice relative to their alternatives. For example, the specific question for Canadian soybean farmers using an insecticide seed treatment was (Hurley and Mitchell 2014, p. 84):

Please think carefully about all the reasons why you chose to plant soybean with an insecticide seed treatment in 2013 and what else you could have done to manage insects instead of using an insecticide seed treatment. ***Compared to these alternatives, what additional value would you say using an insecticide seed treatment provided to you per acre of treated soybean?***

- *Not more than $5 per acre*
- *More than $5, but not more than $10 per acre*
- *More than $10, but not more than $15 per acre*
- *More than $15, but not more than $25 per acre*
- *More than $25 per acre*

This approach is a common method of non-market valuation technique, specifically, an indirect, stated preference, contingent valuation approach using an interval response format (U.S. NAS 2004, p. 101). Responses to value questions of this sort are used to estimate the full value of the practice, not just the direct monetary benefits due to higher yields and/or lower cost but also the non-monetary benefits of these pest management practices, such as safety, convenience and risk reduction. Many market-based methods (such as Mitchell 2015) do not capture these non-monetary (also called non-pecuniary) values.

The econometric methods used to analyze the survey data and responses to these questions are fairly technical and are described in detail in Hurley and Mitchell (2014). Here we focus on the final results and just for Canadian corn and soybean farmers (the full report includes similar results for Canadian canola farmers and U.S. corn and soybean farmers). The final results of interest here are the additional value that farmers who use the different pest management practices derive from using them, specifically neonicotinoid seed treatments and foliar-applied insecticides for both corn and soybean farmers and Bt corn for corn farmers. Among Canadian corn farmers, only two farmer responses were collected for soil-applied insecticides used in corn, which was insufficient to estimate value.

Table 9 reports the econometrically-derived estimates of farmer values for the different pest management practices for corn and soybean for the pooled Canadian data and for three Canadian provinces separately. These are the values reported in Hurley and Mitchell (2014), pp. 40-42, after conversion to Canadian dollars per hectare. These results are the value per treated hectare for those farmers using these practices. A value for foliar-applied insecticides in corn is only reported for the pooled Canadian

Table 9. Estimated net farmer value ($ per treated ha) for Canadian corn and soybean farmers for different insect control methods based on survey data analysis

Treatment and Crop	Canada	Manitoba	Ontario	Quebec
Neonicotinoid Seed Treatment				
Corn	$32.27	$29.32	$34.61	$26.85
Soybean	$39.01	$43.63	$38.63	$35.33
Foliar Insecticide				
Corn	$39.60	---*	---*	---*
Soybean	$27.01	$27.81	$24.24	$32.16
Bt Corn	$53.83	$51.82	$47.68	$68.73

Source: Hurley and Mitchell (2014), pp. 40-42.

*Insufficient data to estimate value.

Table 10. Aggregate farmer value ($ million) for Canadian corn and soybean farmers for different insect control methods, estimated using non-market valuation methods and survey data

Treatment	Corn	Soybean	Total
Neonicotinoid Seed Treatment	$36	$47	$83
Foliar Insecticide	$3	$3	$6
Bt Corn	$61	---*	$61

Source: Hurley and Mitchell (2014), pp. 44.

data because there were not enough responses in each province to estimate province-specific values. These values are estimates of the full value of each practice, net of the cost and relative to the available alternatives. As a full value, these estimates capture both the direct monetary value from increased yields and/or lower costs as well as the indirect benefits, such as from reduced risk, improved safety and convenience of use.

The results in Table 9 for corn show that on a per hectare basis, Bt corn is the most valued pest management practice among Canadian corn farmers, with values ranging from almost $48/ha in Ontario to almost $69/ha in Quebec and almost $54/ha the estimate for the pooled Canadian data. More than 90% of Canadian corn farmers report using Bt corn, with more than 76% reporting using Bt corn with both corn borer and rootworm traits as well as almost 12% using Bt corn with only a rootworm trait (Hurley and Mitchell 2014, p. 20). As a result, most of this Bt corn has traits for controlling rootworm and so is sold with a low rate of a neonicotinoid seed treatment (plus the high rate used on non-Bt corn seed as part of an overall insect resistance management strategy mandated by the Canadian Food Inspection Agency). Thus, these value estimates for Bt corn are a mix of values for the specific Bt traits and the neonicotinoid seed treatments.

Table 9 also reports estimates of farmer values for neonicotinoid seed treatments used alone. Values range from almost $27/ha in Quebec to about $35/ha in Ontario, with the pooled Canadian estimate of more than $32/ha. Finally, Table 9 also reports a pooled Canadian estimated value of almost $40/ha for the few corn farmers reporting using foliar-applied insecticides.

The results for soybean in Table 9 for neonicotinoid seed treatments show farmer values ranging from more than $35/ha in Quebec to approximately $44 in Manitoba, with a pooled Canadian estimate of $39/ha. Farmer values for foliar-applied insecticides range from $24/ha in Ontario to $32/ha in Quebec, with a pooled Canadian estimate of $27/ha.

Overall, these results summarized in Table 9 suggest that Canadian corn and soybean farmers derive substantial benefits from using neonicotinoid seed treatments, both as a part of rootworm Bt corn and by themselves on corn and soybeans. Next, these benefits are aggregated to the national level by using the seeded areas for each crop and the usage rates for each pest management practice. For example, for soybean neonicotinoid seed treatments, the value of $39.01/ha in Table 9 is multiplied by 66.2% (the percent-

age of soybean seeded area treated with neonicotinoid seed treatments in Table 6) and multiplied by 1,829,000 ha of soybean seeded in 2013 to give $47.3 million, the value reported in Table 10.

The results in Table 10 show that neonicotinoid seed treatments are the most valued insect management practice by Canadian corn and soybean farmers. When used alone, the aggregate value for neonicotinoid seed treatments is $83 million per year, $47 million for soybean growers and $36 million for corn growers. Furthermore, neonicotinoid seed treatments contribute some part of the $61 million value of Bt corn, since most of the Bt corn contains the rootworm Bt trait and so is sold with a low rate neonicotinoid seed treatment. Foliar-applied insecticides in total only generate $6 million of value for Canadian corn and soybean farmers, while so few corn farmers used soil-applied insecticide that no value could be estimated.

Table 10 shows that from the perspective of Canadian corn and soybean farmers, insect management is almost exclusively a seed-based decision, either as Bt corn or seed treatments. Foliar- and soil-applied insecticides are a minor part of their insect management system. Also, note that the values summarized in Table 10 are not just the value of increased yields and/or lower costs but also capture the value of improved human and environmental safety, risk reduction and convenience. As Table 8 shows, these factors are important when Canadian corn and soybean farmers make pest management decisions and in the case of human and environmental safety, can actually outweigh the value of improved crop protection and agronomic concerns. These types of non-monetary factors make an important contribution to the value of neonicotinoid insecticides to Canadian corn and soybean farmers.

Theme 4: Listening to Ontario Growers and Agri-Business Professionals

An important part of the PMRA process in crafting a draft report was to incorporate available agronomic, entomological and economic data. The PMRA is to be acknowledged for the level of pest management and farm management knowledge reflected in the draft report — a feature not found the in U.S. EPA draft report on soybeans (Johansson, 2015). This knowledge was used to generate an economic estimate of neonicotinoid seed treatment value at the industry level for corn and soybeans. This aggregate approach is understandable due to the significant variability in soils, weather patterns (i.e., "lake effects"), pest composition and population dynamics as well as all the factors managed by each individual producer such as varietal selections, tillage systems, crop rotations and of course, pest management.

Yet two cautions need to be employed in relying only on the industry calculation of economic value. First, as discussed in the previous sections, there are different analytical techniques that can be used to generate value estimates. These different techniques are likely to produce different economic estimates and serves as a justification for the comprehensive approach illustrated in Figure 1. Second, while quantitative models and accounting can provide definitive numbers, they cannot capture the insights and knowledge that producers and agri-business professionals have accumulated regarding the value of different pest management strategies. These individuals are in an excellent position to provide wisdom on what might happen — beyond economic value — if access to neonicotinoids were restricted further. The observations of these growers and professionals can provide powerful insights regarding values that are not necessarily reflected in quantitative modeling or a cost/benefit analysis of industry impacts. The following represents one such effort of listening to Ontario corn and soybean growers regarding pest management and the role of neonicotinoids in that process.

In order to gain insights and perspective from the grower community, an all-day listening session was organized for March 20th, 2014 at the Four Points by Sheraton London Hotel (1150 Wellington Road South), Ontario. The meeting was by invitation only and ran from 10:30am to 3:30pm. AgInfomatics worked with local agri-business to identify commercial growers and agri-business professionals from the region who managed representative farms or had extensive experience in pest management. AgInfomatics contacted the suggested names, explained the setting and purpose of the listening session and queried whether the grower would be interested in participating. They were also asked to identify other local growers who might be interested in participating. All growers were offered a modest honorarium and travel expenses to participate. This recruitment process resulted in ten growers who participated in the panel, and 14 agri-business representatives in the audience.

Among the many topics and issues raised at the listening session, only two will be used as a contribution to this report. Yet the context for this limited reporting was clearly established by a Canadian grower who stated, "I don't gamble, I manage risk." For these growers pest management is a form of risk management. Restricting or eliminating an effective and popular systemic insecticide changes the risk calculations in a number of areas related to farm management. The listening session became an interesting dialogue on identifying changes, remedial strategies and consequences of a fundamental change in prevailing risk management practices.

The first topic directly addresses the counterfactual question of what would happen if neonicotinoids were no longer available. Growers and agri-business professionals had given the question some thought prior to coming to the session — as they came with detailed examples and calculations as to likely impacts. The second topic was heard across the listening session but became most pronounced toward the end of the overall session. This was the frustration the panelists voiced on proposals to do away with neonicotinoids without persuasive scientific evidence to support that decision. In a way, the discussion flowed logically; here are the likely impacts of losing neonicotinoids, we can make some adjustments but significant problems remain and exasperation with the perception that emotion, as opposed to objective data, is being reported in the media is influencing a policy decision.

Impacts of Losing Neonicotinoids

Panel members identified a number of impacts associated with pest management, machinery and costs to the operation. This report will identify

possible impacts that are not covered in the quantitative modeling but are part of the values analyzed in the Hurley and Mitchell (2014) analysis.

One of the likely impacts identified early in the panel discussions was the likely impact on pollinators and other beneficial insects with the loss of neonicotinoids. Shifting pest management over to foliar applications exposes all insects — pest and beneficial — to the insecticide unlike the systemic action of neonicotinoids. One grower noted,

> "We're going to see increased use of foliar application of insecticides. And this isn't the way we want to go, but it's just what's going to happen. We as farmers don't get up at 5:30 in the morning saying 'We want to get out there and kill those insects!' That is not something we do. It is a last resort we have. But in this case it may force our hand."

Or as another grower put it,

> "If I have to go out and spray Matador® for aphids in July or August, there's not a honeybee going back to the hive then, nor beneficials that we want in the crop, it's going to affect them as well."

Another grower supported this last statement by stating,

> "The use of neonics allows us integrated pest management because when we talk about the aphids and the ladybugs, I mean the only reason that we've got ladybugs there is because we don't have to go in and hammer a crop to kill the aphids."

Being forced to return to depending on foliar sprays to control insect pests would also increase the number of lawsuits filed by beekeepers against growers. A grower expressed this view by stating,

> "If we start spraying more foliar insecticides which I believe will kill more bees — and there's precedent set here in the province with people suing people who have killed their hives from foliar insecticide applications."

The conversation shifted from impacts on pollinators to the role of integrated pest management in Ontario crop production. Panelists believe that the use of neonicotinoids advanced integrated pest management because, "it's allowed us to be more targeted too because now with neonics you can scout and we just spray when needed." This idea of neonicotinoids allowing 'targeted' sprays was reinforced when discussing what would happen without neonicotinoids. The panel members identified two likely outcomes, both increasing the use of foliar applications. First, without neonicotinoids, if a grower sees a neighbor spraying, then it is likely that grower will also spray. Second, the targeted or limited remedial spraying will likely end as "if you get a recommendation on a couple hundred acres you're going to spray the rest." The panel was unable to provide an estimate of the costs to the farm operation or human health and environmental impacts of this increased spraying.

A significant amount of discussion centered on the issue of whether growers could move back to a pest management system based on foliar applications.

Topics addressed included the availability of insecticides to manage the pests currently being controlled with neonicotinoid seed treatments, sprayer capacity in the province, availability of scouting expertise (either on-farm or local consultants) and the impacts of returning to the pest management of an earlier era. Growers with newer planters no longer have pesticide boxes built into the unit, and this means significant retrofit expenses, while decreasing the seed capacity of the planter. A grower had calculated the cost of this conversion to be $862 per planter row, decreasing capacity by 47%.

An interesting observation was made about how pest management has changed since the introduction of neonicotinoids and what this means to younger growers.

> "We used to always get out in the field to see the seed corn maggot and wireworms, the younger farmers they haven't seen those so they don't know what they're looking for or what the damage looks like."

The point being made is that without neonicotinoids there will have to be a significant investment in training and educational programs on scouting and identifying pests currently controlled by neonicotinoids. This is related to another issue raised later in this section of the report. The loss of neonicotinoids would be moving backward in pest management, and as noted here, many of the younger growers do not have the knowledge or experience with those pest management practices.

There was consensus on the panel that spraying would increase with the loss of neonicotinoids.

> "Would spraying increase? Yes. Astronomically. Because if we go back to what was happening in 2003 with aphids as an example, we had a major infestation, I mean there was hundreds of thousands of acres sprayed, and if we go into last year where you had aphid sprays and I'll speak seed companies for a second — when we offered out fungicide-treated seed this year, we expected that we would see the fungicide treatment go way up and spraying go way down … but insecticide sales went way up because the guys that had Cruiser Maxx® treatment on their soybeans they didn't have to spray but everyone else did. So the volume of spray would go way up. If I had to look at my own farm I'm going to have to budget two leafhopper sprays minimum, right off the bat, guaranteed. Compared to none today. Soybeans, I'm going to have to, guarantee, probably put a spray in my aphids, which I don't today, because ladybugs build their population and away they go. So, astronomical impact."

Consistent with the findings in the Gaspar et al., (2015) paper discussed earlier, these growers were aware of the changes in seeding rates when using insecticide seed treatments. One of the growers mentioned the former practice of 'giving some seed to the insects' versus the lower seed populations used currently.

> "It's actually a significant amount of acres. We've taken our populations from about 200,000 to165,000 or168,000 because every one comes up. We're not guessing at how many bugs were going to get them like we did a few years ago…. so we've saved a considerable amount of seed."

Another theme that emerged in many comments and represents a resource not considered in quantitative budget calculations is the increase in the time required to practice pest management.

> "Let's not discount our labor costs, the service calls, going to the field, hand-ringing, worrying … it all takes times … you're going to do a lot of assessments practicing IPM and trying to figure out thresholds for the course of action — all that stuff is time and money."

Another dimension of this issue could be characterized as timeliness. This refers to the notion that when an action has to occur can be as important, if not more important, than the amount of time it takes to conduct the action. Growers recognized this in several ways. Needing custom application of a foliar-applied insecticide will depend on achieving threshold levels, but getting that sprayer will depend on local availability. If all local custom applicators are busy, a likely scenario in a pest infestation. Then there is a strong likelihood that pest damage will occur before the application can take place. Related to this is the need to spray versus the environmental conditions that will allow you to spray.

> "It's important to talk about the technology aspect of it too, because it's easy enough just to talk about spraying, but if you've got an insect issue you maybe can't wait until it's calm enough to do the job — the wind isn't blowing from the wood lot or sensitive areas and that type of thing, so you're basically doubling down on your capacity because the window can be too short to do the job."

The point being made by these growers is that there will be a number of costs and negative trade-offs associated with the loss of neonicotinoids. Shifting to foliar applications of insecticides will mean increased time and costs associated with pesticide safety. As one of the growers stated,

> "We're supposed to be compliant now but for those that aren't you're going to have to step up … so the training costs — you're looking at about fifteen hundred, two thousand dollars per employee to keep their training up — per employee and roughly every year. By the time you replace safety equipment and do the training, and you've got to bring them in on regular meetings which means they're not on the job doing their tasks…"

They also expressed concern that many of them farm adjacent to suburban or rural non-farm residences, and this setting raises significant concerns related to human health and safety. As cited by one grower when referencing another's situation,

> "He's got land right inside the city of London limits, he goes out and sprays Matador® or Saigon® and some kid's soccer ball runs in there, what's to stop him from running in to get his soccer ball."

Another impact that emerged was related to the environment in the form of cover crops. Several growers had been involved with introducing cover crops to their area in an effort to protect water quality and build soil tilth. The growers noted that cover crops were not feasible prior to the introduction of neonicotinoid seed treatments. The increased soil organic matter derived from the cover crop also serves as an ideal habitat for certain soil pests.

> "Twenty-five years ago someone told me my corn looked really crappy … I used to use a cover crop, and I had to stop using it until I got the neonics."

Growers believed that government programs promoting cover crops as part of soil stewardship would suffer a significant setback with the loss of neonicotinoids due to cover crops going out while tillage increases. The growers noted that the foliar application of available insecticides will not control certain soil pests, and increased tillage was the only option.

The Loss of Neonicotinoids

After spending the morning and early afternoon discussing likely impacts associated with the counterfactual question, the discussion began to focus on the emergence and motivations behind the demands for a ban on neonicotinoids in Ontario. Approximately half of the growers on the panel either had neighbors who kept bees, or there were bees proximate to rented land. One of these growers stated,

> "I made an option of talking to two large beekeepers just about their perspective. How many bees have they lost and what's the health of their hives? Both of them have had never better bees! And I plant my crops right around their hives, and I'm thinking what's going on? Are we hearing just from a select few? Whose perspective are we hearing?"

None of the panel could recall an instance where there were significant losses associated with beekeepers in their area.

> "Unfortunately in Ontario, I've read that 80% of the beekeepers are amateur beekeepers, they're doing it after they retire, so there's not that many large-scale ones. On my own farm, five years ago if someone wanted to put hives there I'd say 'Sure, no problem.' Now I wouldn't touch them — no hives on our property. So they're kind of hurting themselves."

Part of the discussion could be characterized as frustration with media portrayals of how Ontario agriculture is harming pollinators. Most panelists viewed this characterization as lacking a scientific foundation and instead, being based on emotion, stereotype and an agenda to ban all pesticides.

> "We're kind of robbing Peter to pay Paul here, in a certain sense, if you want to get rid of neonicotinoids than you're going to kill more bees with the sprays. That's almost a 100% for sure. So it makes no sense to me at all to do that, the ban on neonicotinoids. I'm sure there are a certain percentage of bees that are dying because of the neonicotinoids, but I'm also sure it's very, very small. And the media has blown it all out of proportion. We need to stand up for ourselves and say 'Hey, you guys are wrong. Prove to us with science that we're killing all of these bees first.' And they're not doing it, as far as I can see."

There was also a directionality contained in the panel discussion when thinking of changing pest management to be developed around scouting, thresholds and foliar applications of insecticides. The growers clearly

viewed the alternatives to neonicotinoids (i.e., foliar sprays of insecticides) as moving backwards or returning to the farming practices of the past. Discussion on how so many of the inputs, from genetics to pesticides and more, were all 'stacked' on the seed allowing the grower to focus management on topics related to marketing, precision applications or stewardship. The technologies represented by these 'stacked' inputs and much of the innovation occurring in modern agriculture, implies that the pest management of tomorrow has to be very different from the pest management of yesteryear. If other innovative seed technologies continue to be developed and are adopted in the U.S., and neonicotinoids are banned or restricted in Ontario, then these growers said this would be a distinct disadvantage in a very competitive global market.

At the end of the listening session the growers were asked to provide a summary or overview statement based on all they heard at the session. While there were many important observations, the following best summarizes the insights and experiences shared by these growers.

> "I think one of the biggest things to pass on is that we're all stewards of the land, we all want to see it improve, we all have family and want to see them be healthy, but I think we all agree that the neonics are still the best solution for all the local communities in the province. So, why are we losing them? I think we need them for financial reasons as well as social, and there's a responsibility here to be safe to our workers and the public and everyone else. To me it seems preposterous that we're facing the possibility of losing them."

Summary

There are multiple types of value generated by crop production and pest management practices such as neonicotinoid seed treatments, and there are many different ways to estimate some of these values. The U.S. EPA (2010) report *Guidelines for Preparing Economic Analyses* summarizes several of these methods and approaches in the context of regulatory decision making. The 15 AgInfomatics reports (available online at (http://growingmatters.org/studies/) have used several of these methods and approaches to develop a robust view of the benefits of neonicotinoid insecticides in North America using a data triangulation approach (Figure 1). This report distills some of the results from these reports, focusing on corn and soybeans grown in Canada. Additional information has also been incorporated into this report based on our on-going research and our experiences summarizing and presenting these results to a variety of audiences over the last several months.

First, additional yield data from Canadian small plot studies were identified and added to the soybean yield meta-analysis, so that updated estimates of the yield benefit of neonicotinoid seed treatments were developed for Canada corn and soybean. For Canadian corn, the yield benefit averaged 11.1% compared to untreated seed (70 observations) and 9.8% compared to alternative insecticide treatments (30 observations) See Table 1. For Canadian soybeans, the yield benefit averaged 8.5% compared to untreated seed (119 observations) and 1.6% compared to alternative insecticide treatments (88 observations). See Table 2.

Second, the results from a recently published paper by Gaspar et al. (2015) were summarized and the implications for use of neonicotinoid seed treatments described. The concept of managerial significance was introduced as an alternative to the more traditional statistical significance that is more useful to understand the pest management choices that farmers face and to develop management recommendations. More specifically, statistical significance requires that the beneficial effect a treatment has on yield or profit is sufficiently large and certain, so that if the experiment were repeated, 95% of the time the beneficial treatment effect would occur. However, farmers and other decision makers do not typically require that level of certainty. Managerial significance examines the average benefit and the breakeven profitability (the likelihood that if the treatment is used, the return will equal or exceed the cost of the treatment) and lets the farmer decide if the risk and reward are sufficient to use the practices. The specific example from Gaspar et al. (2015), based on two years of data from nine locations in Wisconsin, is the finding that the average return to using a neonicotinoid seed treatment is an average gain of $50 to $74/ha, with a 86%-89% probability to generate enough yield gain to pay for the seed treatment (Table 4). These probabilities imply that many farmers would find the gain and probabilities managerial significant and use the seed treatment.

Third, various results were highlighted from a telephone survey of U.S. and Canadian corn, soybean and canola farmers. Focusing on the 240 Canadian corn and soybean farmers, corn borer and corn rootworm are the major corn pests and soybean aphids the major soybean pest they manage, with a long list of more minor pests they manage in both crops, several of them soil-dwelling or early season pests (Table 5). Neonicotinoid seed treatments and Bt corn (most of which contain a rootworm Bt trait and so also has a neonicotinoid seed treatment) are by far the most common insect management practices used. Three-fourths of corn uses both practices and two-thirds of soybeans use seed treatments; only 5%-7% of corn and soybeans use foliar-applied insecticide and only 3% of corn uses soil insecticides (Table 6). Seed-based pest mange practices dominate Canadian corn and soybean production. As a result, it was not surprising that two-thirds of Canadian corn and soybean farmers reported that they would still prefer to buy neonicotinoid seed treatments on their seed, even if the same varieties were available without the seed treatment (Table 7). When asked about how important various factors are when making pest management decisions, human and environmental safety are the most important factors Canadian corn and soybean farmers mention. Crop protection and agronomic factors are secondary, while economic and convenience factors are the least important (Table 8). These results suggest that Canadian farmers are tremendous allies in the appropriate use of insecticides for the public good and their concerns can be used to achieve publicly desirable outcomes by working with farmers.

Fourth, as part of this same telephone survey, contingent valuation questions were included to estimate the value farmers derive from the different pest management practices they use. This is a comprehensive value estimate, encompassing not just the value of increased yield and reduced cost but also non-monetary benefits, such as improved human and environmental safety, reduced yield risk and increased convenience of application. Econometric analysis found that the farmer value of neonicotinoid seed treatments were

about $39/ha for soybeans and $32/ha for corn (Table 9). Because most of the Bt corn included rootworm Bt traits and so is sold with a neonicotinoid seed treatment, a portion of the almost $54/ha farmer benefit for Bt corn is derived from the seed treatment. These farmer values are $ per hectare treated, and so multiplying by the treated area for each practice gives an aggregate estimate of the total farmer value for each pest management practice. Based on this calculation, neonicotinoid seed treatments are the most valuable pest management practice for Canadian corn and soybean farmers. The value of neonicotinoid seed treatments is $47 million for soybean farmers and $36 million for corn farmers, for a total value of $83 million, while the total farmer value of Bt corn is $61 million (Table 10). The value placed by farmers on foliar insecticide applications was only $6 million, $3 million each for corn and soybean, while so few soil insecticides were used that no values could be estimated.

These results help provide a robust and nuanced view of the benefits of neonicotinoid seed treatments as used on corn and soybeans in Canada. They generate substantial yield benefits, even when compared to alternative soil and foliar applied insecticides, even the small 1.6% soybean yield gain relative to a foliar insecticide, as demonstrated by the example partial budget analysis. The benefits they provide do not always satisfy the traditional statistical significance requirement, but the work of Gaspar et al. (2015) in Wisconsin shows their benefits can be managerially significant — implying a $50 to $74/ha average gain with an 86%-89% probability of generating enough yield to equal or exceed the cost of the treatment.

In short, neonicotinoid seed treatments are the most valued insect management practice used by Canadian corn and soybean farmers, worth an estimated $83 million per year based on a contingent valuation survey. They also contribute to the $61 million value from Bt corn, far exceeding the $6 million farmer value for foliar-applied insecticides. From the farmer perspective, a significant portion of this value is likely generated by the human and environmental safety of neonicotinoid seed treatments relative to foliar- and soil-applied insecticides.

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Appendix A

Appendix Table A1. Canadian corn yield data used for meta-analysis

			------------- Yield (Mg/ha) -------------		
Reference	**Location**	**Year**	**Control**	**Neonicotinoid**	**Alternative**
Kabaluk & Ericsson (2007)	British Columbia	2006	7.9	10.6	7.4
Kullick et al. (2004)	Woodstock, ON	2004	10.4	10.9	---
Kullick et al. (2004)	Woodstock, ON	2004	11.5	11.7	---
Kullick et al. (2004)	Dunnville, ON	2004	6.2	6.6	---
Kullick et al. (2004)	Dunnville, ON	2004	6.7	7.0	---
Kullick et al. (2004)	Dunnville, ON	2004	7.1	7.1	---
Kullick et al. (2004)	Dunnville, ON	2004	8.6	6.6	---
Kullik et al. (2003)	Long Point, ON	2003	3.8	4.4	---
Kullik et al. (2003)	Long Point, ON	2003	6.0	5.7	---
Kullik et al. (2003)	Dunnville, ON	2003	10.2	10.1	---
Kullik et al. (2003)	Dunnville, ON	2003	10.4	10.6	---
Schaafsma et al. (2000)	Ridgetown, ON	2000	7.0	7.8	8.6
Schaafsma et al. (2000)	Ridgetown, ON	2000	6.8	6.1	6.8
Schaafsma et al. (2002a)	London, ON	2002	6.4	6.7	6.0
Schaafsma et al. (2002a)	Ridgetown, ON	2002	4.9	5.6	6.8
Schaafsma et al. (2002a)	Ridgetown, ON	2002	1.0	3.0	2.7
Schaafsma et al. (2002b)	Port Stanley, ON	2002	4.6	4.0	---
Schaafsma et al. (2002b)	Port Stanley, ON	2002	3.0	2.8	2.4
Schaafsma et al. (2002b)	Port Stanley, ON	2002	3.0	4.7	2.4
Schaafsma et al. (2002b)	Port Stanley, ON	2002	3.0	3.8	2.4
Schaafsma et al. (2002c)	Ridgetown, ON	2002	3.1	3.3	3.4
Schaafsma et al. (2002c)	Ridgetown, ON	2002	3.1	3.5	3.4
Schaafsma et al. (2002c)	Ridgetown, ON	2002	3.1	3.7	3.4
Schaafsma et al. (2002d)	Rodney, ON	2002	3.0	2.6	5.8
Schaafsma et al. (2002d)	Rodney, ON	2002	3.0	3.8	5.8
Schaafsma et al. (2002d)	Rodney, ON	2002	3.0	5.7	5.8
Schaafsma et al. (2003a)	Ridgetown, ON	2003	6.9	10.8	10.1
Schaafsma et al. (2003a)	Ridgetown, ON	2003	6.9	9.5	10.1
Schaafsma et al. (2003a)	Ridgetown, ON	2003	11.2	12.7	12.1
Schaafsma et al. (2003a)	Ridgetown, ON	2003	11.2	11.9	12.1
Schaafsma et al. (2003b)	Ridgetown, ON	2003	10.8	13.0	---
Schaafsma et al. (2003b)	Ridgetown, ON	2003	10.8	11.3	---
Schaafsma et al. (2003b)	Ridgetown, ON	2003	10.8	13.0	---
Schaafsma et al. (2003c)	Ridgetown, ON	2003	9.9	11.0	9.4
Schaafsma et al. (2003c)	Ridgetown, ON	2003	9.9	10.3	9.4
Schaafsma et al. (2003c)	Ridgetown, ON	2003	9.9	9.9	9.4

Appendix Table A1 (cointued). Canadian corn yield data used for meta-analysis

Reference	Location	Year	------------- Yield (Mg/ha) -------------		
			Control	Neonicotinoid	Alternative
Schaafsma et al. (2003d)	Ridgetown, ON	2003	9.8	10.5	---
Schaafsma et al. (2003d)	Ridgetown, ON	2003	9.8	11.2	---
Schaafsma et al. (2003d)	Ridgetown, ON	2003	9.8	10.7	---
Schaafsma et al. (2003d)	Wallacetown, ON	2003	5.8	6.8	---
Schaafsma et al. (2003d)	Wallacetown, ON	2003	5.8	6.0	---
Schaafsma et al. (2003d)	Wallacetown, ON	2003	5.8	5.9	---
Schaafsma et al. (2003e)	Rodney, ON	2003	7.4	8.8	---
Schaafsma et al. (2003e)	Rodney, ON	2003	7.4	9.3	---
Schaafsma et al. (2003e)	Rodney, ON	2003	7.4	9.1	---
Schaafsma et al. (2003f)	Rodney, ON	2003	8.8	9.6	9.2
Schaafsma et al. (2003f)	Rodney, ON	2003	8.8	8.8	9.2
Schaafsma et al. (2003f)	Rodney, ON	2003	8.0	9.3	8.8
Schaafsma et al. (2003f)	Rodney, ON	2003	8.0	10.2	8.8
Schaafsma et al. (2004a)	Ridgetown, ON	2004	5.5	7.0	6.5
Schaafsma et al. (2004a)	Ridgetown, ON	2004	1.1	1.5	0.6
Schaafsma et al. (2004c)	Rodney, ON	2004	10.8	10.3	---
Schaafsma et al. (2004c)	Rodney, ON	2004	8.0	8.8	---
Schaafsma et al. (2004d)	Ridgetown, ON	2004	8.0	7.5	---
Schaafsma et al. (2004d)	Ridgetown, ON	2004	8.0	8.9	---
Schaafsma et al. (2005a)	Ridgetown, ON	2005	5.9	5.7	---
Schaafsma et al. (2005a)	Ridgetown, ON	2005	5.9	6.4	---
Schaafsma et al. (2005a)	Ridgetown, ON	2005	4.6	4.2	---
Schaafsma et al. (2005a)	Ridgetown, ON	2005	4.6	6.0	---
Schaafsma et al. (2005b)	Rodney, ON	2005	9.6	10.2	---
Schaafsma et al. (2005b)	Rodney, ON	2005	9.6	10.6	---
Smith et al. (2008a)	Ridgetown, ON	2008	10.4	10.7	---
Smith et al. (2008a)	Ridgetown, ON	2008	10.4	10.1	---
Smith et al. (2008a)	Ridgetown, ON	2008	9.9	10.1	---
Smith et al. (2008a)	Ridgetown, ON	2008	9.9	10.5	---
Smith et al. (2008a)	Ridgetown, ON	2008	9.3	9.7	---
Smith et al. (2008a)	Ridgetown, ON	2008	9.3	9.9	---
Smith et al. (2008a)	Ridgetown, ON	2008	9.5	10.0	---
Smith et al. (2008a)	Ridgetown, ON	2008	9.5	9.6	---
Smith et al. (2009a)	Ridgetown, ON	2009	4.0	4.5	6.0
Smith et al. (2009a)	Ridgetown, ON	2009	4.0	4.3	6.0

Appendix Table A2. Canadian soybean yield data used for meta-analysis

Reference	Location	Year	------------- Yield (Mg/ha) -------------		
			Control	Neonicotinoid	Alternative
Hooker et al. 2012	Exeter, ON	2008	3.2	3.3	3.1
Hooker et al. 2012	Exeter, ON	2008	3.6	3.6	3.2
Hooker et al. 2012	Exeter, ON	2008	3.2	3.2	3.2
Hooker et al. 2012	Exeter, ON	2008	3.5	3.5	3.0
Hooker et al. 2012	Exeter, ON	2008	3.2	3.5	3.2
Hooker et al. 2012	Exeter, ON	2008	3.6	3.6	3.4
Hooker et al. 2012	Exeter, ON	2008	3.1	3.2	3.2
Hooker et al. 2012	Exeter, ON	2008	3.4	3.3	3.5
Hooker et al. 2012	Exeter, ON	2008	2.8	2.6	2.6
Hooker et al. 2012	Exeter, ON	2008	2.8	2.5	2.6
Hooker et al. 2012	Exeter, ON	2008	3.0	2.9	2.8
Hooker et al. 2012	Exeter, ON	2008	2.6	2.8	2.5
Hooker et al. 2012	Exeter, ON	2008	2.5	2.7	2.9
Hooker et al. 2012	Exeter, ON	2008	2.9	2.7	2.7
Hooker et al. 2012	Exeter, ON	2008	2.7	3.0	2.8
Hooker et al. 2012	Exeter, ON	2008	2.4	2.5	2.6
Hooker et al. 2012	Ridgetown, ON	2008	3.4	3.4	3.6
Hooker et al. 2012	Ridgetown, ON	2008	3.2	3.4	3.6
Hooker et al. 2012	Ridgetown, ON	2008	3.3	3.5	3.5
Hooker et al. 2012	Ridgetown, ON	2008	3.4	3.5	3.7
Hooker et al. 2012	Ridgetown, ON	2008	3.3	3.3	3.1
Hooker et al. 2012	Ridgetown, ON	2008	3.1	3.5	2.8
Hooker et al. 2012	Ridgetown, ON	2008	3.1	3.2	3.1
Hooker et al. 2012	Ridgetown, ON	2008	3.0	3.5	2.8
Hooker et al. 2012	Exeter, ON	2009	2.8	3.0	3.0
Hooker et al. 2012	Exeter, ON	2009	3.1	3.1	3.0
Hooker et al. 2012	Exeter, ON	2009	2.7	2.9	2.8
Hooker et al. 2012	Exeter, ON	2009	2.9	2.9	2.7
Hooker et al. 2012	Exeter, ON	2009	3.0	3.0	3.0
Hooker et al. 2012	Exeter, ON	2009	3.1	3.1	2.9
Hooker et al. 2012	Exeter, ON	2009	2.9	3.1	3.0
Hooker et al. 2012	Exeter, ON	2009	3.1	3.3	3.1
Hooker et al. 2012	Exeter, ON	2009	2.3	2.6	2.7
Hooker et al. 2012	Exeter, ON	2009	2.2	2.5	2.5
Hooker et al. 2012	Exeter, ON	2009	2.4	2.5	2.5
Hooker et al. 2012	Exeter, ON	2009	2.4	2.4	2.5
Hooker et al. 2012	Exeter, ON	2009	2.8	2.7	2.8
Hooker et al. 2012	Exeter, ON	2009	2.8	2.7	3.0

Appendix Table A2 (continued). Canadian soybean yield data used for meta-analysis

Reference	Location	Year	Control	Neonicotinoid	Alternative
			------------- Yield (Mg/ha) -------------		
Hooker et al. 2012	Exeter, ON	2009	2.5	2.8	2.7
Hooker et al. 2012	Exeter, ON	2009	2.4	2.9	2.6
Hooker et al. 2012	Ridgetown, ON	2009	3.5	4.0	3.7
Hooker et al. 2012	Ridgetown, ON	2009	3.6	4.0	3.8
Hooker et al. 2012	Ridgetown, ON	2009	3.7	3.9	3.8
Hooker et al. 2012	Ridgetown, ON	2009	3.5	4.1	3.8
Hooker et al. 2012	Ridgetown, ON	2009	3.6	4.0	3.8
Hooker et al. 2012	Ridgetown, ON	2009	3.9	4.1	3.9
Hooker et al. 2012	Ridgetown, ON	2009	3.6	3.9	4.0
Hooker et al. 2012	Ridgetown, ON	2009	3.8	4.2	3.9
Hooker et al. 2012	Ridgetown, ON	2009	3.5	3.2	3.5
Hooker et al. 2012	Ridgetown, ON	2009	3.3	3.4	3.6
Hooker et al. 2012	Ridgetown, ON	2009	3.3	3.5	3.5
Hooker et al. 2012	Ridgetown, ON	2009	3.2	3.2	3.5
Hooker et al. 2012	Ridgetown, ON	2009	3.1	3.2	3.6
Hooker et al. 2012	Ridgetown, ON	2009	3.2	3.1	3.8
Hooker et al. 2012	Ridgetown, ON	2009	3.1	3.3	3.5
Hooker et al. 2012	Ridgetown, ON	2009	3.1	3.4	3.6
Hooker et al. 2012	Exeter, ON	2010	4.5	4.6	4.6
Hooker et al. 2012	Exeter, ON	2010	4.5	4.8	4.4
Hooker et al. 2012	Exeter, ON	2010	4.7	4.4	4.4
Hooker et al. 2012	Exeter, ON	2010	4.7	4.5	4.5
Hooker et al. 2012	Exeter, ON	2010	4.7	4.4	4.7
Hooker et al. 2012	Exeter, ON	2010	4.5	4.4	4.2
Hooker et al. 2012	Exeter, ON	2010	4.8	4.7	4.4
Hooker et al. 2012	Exeter, ON	2010	4.6	4.7	4.3
Hooker et al. 2012	Exeter, ON	2010	3.3	3.7	3.2
Hooker et al. 2012	Exeter, ON	2010	3.1	3.1	3.6
Hooker et al. 2012	Exeter, ON	2010	2.9	3.3	3.2
Hooker et al. 2012	Exeter, ON	2010	3.6	3.6	3.8
Hooker et al. 2012	Exeter, ON	2010	3.4	3.6	3.9
Hooker et al. 2012	Exeter, ON	2010	3.4	3.6	3.6
Hooker et al. 2012	Exeter, ON	2010	3.3	3.2	3.8
Hooker et al. 2012	Exeter, ON	2010	3.7	3.2	3.9
Hooker et al. 2012	Ridgetown, ON	2010	4.2	4.6	4.5
Hooker et al. 2012	Ridgetown, ON	2010	4.3	4.7	4.4
Hooker et al. 2012	Ridgetown, ON	2010	4.3	4.8	4.3
Hooker et al. 2012	Ridgetown, ON	2010	4.5	4.7	4.2

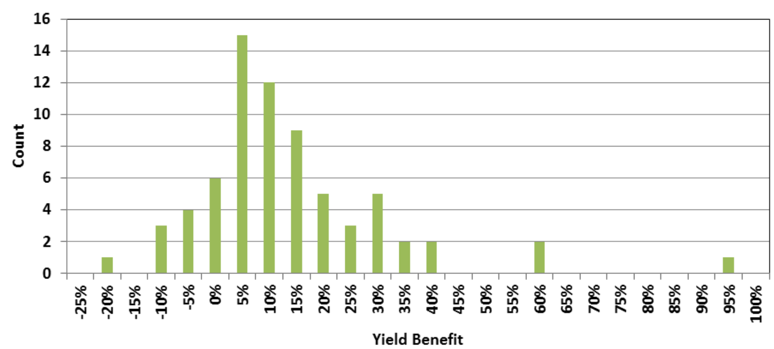
Appendix Table A2 (continued). Canadian soybean yield data used for meta-analysis

			Yield (Mg/ha)		
Reference	**Location**	**Year**	**Control**	**Neonicotinoid**	**Alternative**
Hooker et al. 2012	Ridgetown, ON	2010	4.2	4.3	4.3
Hooker et al. 2012	Ridgetown, ON	2010	4.3	4.5	4.5
Hooker et al. 2012	Ridgetown, ON	2010	4.4	4.3	4.3
Hooker et al. 2012	Ridgetown, ON	2010	4.3	4.5	4.4
Hooker et al. 2012	Ridgetown, ON	2010	4.1	4.1	4.2
Hooker et al. 2012	Ridgetown, ON	2010	4.1	4.2	4.4
Hooker et al. 2012	Ridgetown, ON	2010	3.9	3.9	4.0
Hooker et al. 2012	Ridgetown, ON	2010	4.3	4.1	4.0
Hooker et al. 2012	Ridgetown, ON	2010	4.2	4.1	4.0
Hooker et al. 2012	Ridgetown, ON	2010	4.2	4.1	4.1
Hooker et al. 2012	Ridgetown, ON	2010	3.9	3.8	3.7
Hooker et al. 2012	Ridgetown, ON	2010	4.1	4.3	4.1
Schaafsma et al. 2001	Ridgetown, ON	2001	3.9	4.1	---
Schaafsma et al. 2002f	Ridgetown, ON	2002	4.6	2.7	---
Schaafsma et al. 2002f	Ridgetown, ON	2002	4.6	4.8	---
Schaafsma et al. 2002f	Ridgetown, ON	2002	4.6	5.0	---
Schaafsma et al. 2002e	Ridgetown, ON	2002	0.6	1.0	---
Schaafsma et al. 2003g	Ridgetown, ON	2003	5.7	6.1	---
Schaafsma et al. 2003g	Ridgetown, ON	2003	5.7	7.1	---
Schaafsma et al. 2003g	Ridgetown, ON	2003	5.7	7.2	---
Schaafsma et al. 2003h	Ridgetown, ON	2003	4.0	5.1	---
Schaafsma et al. 2003h	Ridgetown, ON	2003	4.0	5.9	---
Schaafsma et al. 2003h	Ridgetown, ON	2003	4.0	6.1	---
Schaafsma et al. 2004b	Ridgetown, ON	2004	2.8	2.7	---
Schaafsma et al. 2004b	Ridgetown, ON	2004	2.1	2.5	---
Schaafsma et al. 2005c	Ridgetown, ON	2005	3.7	3.4	---
Schaafsma et al. 2005c	Ridgetown, ON	2005	0.8	0.8	---
Schaafsma et al. 2005c	Ridgetown, ON	2005	2.2	2.3	---
Schaafsma et al. 2006a	Ridgetown, ON	2006	0.5	0.5	---
Schaafsma et al. 2006a	Ridgetown, ON	2006	0.5	0.6	---
Schaafsma et al. 2006b	Rodney, ON	2006	0.6	1.3	---
Schaafsma et al. 2006b	Rodney, ON	2006	0.6	1.4	---
Schaafsma et al. 2006c	Ridgetown, ON	2006	1.1	2.6	---
Schaafsma et al. 2006c	Ridgetown, ON	2006	0.5	2.7	---
Schaafsma et al. 2008b	Ridgetown, ON	2008	2.2	2.7	---
Schaafsma et al. 2008b	Ridgetown, ON	2008	2.2	3.8	---
Schaafsma et al. 2009b	Ridgetown, ON	2009	3.0	2.7	---
Schaafsma et al. 2009b	Ridgetown, ON	2009	3.0	2.7	---

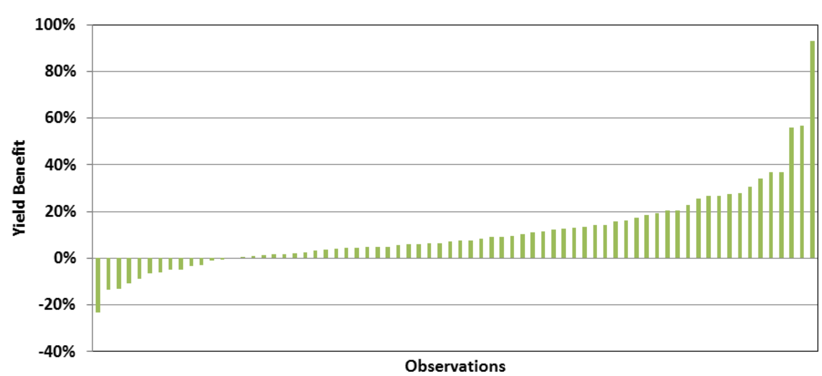
Appendix Table A2 (continued). Canadian soybean yield data used for meta-analysis

Reference	Location	Year	Control	Neonicotinoid	Alternative
			------------- Yield (Mg/ha) -------------		
Schaafsma et al. 2009b	Ridgetown, ON	2009	3.0	2.8	---
Schaafsma et al. 2009b	Ridgetown, ON	2009	3.0	2.8	---
Schaafsma et al. 2009b	Ridgetown, ON	2009	2.9	2.9	---
Schaafsma et al. 2009b	Ridgetown, ON	2009	2.9	3.0	---
Schaafsma et al. 2009b	Ridgetown, ON	2009	2.3	2.5	---
Schaafsma et al. 2009b	Ridgetown, ON	2009	2.3	2.6	---

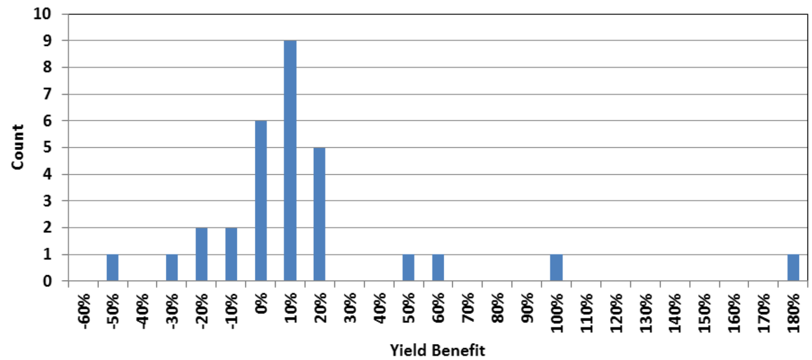
Appendix Figure A1. Histogram of Canadian corn yield benefits for neonicotinoid treatments relative to untreated control treatments (N = 70, minimum = –23.26%, maximum = 93.22%, average = 11.07%, standard deviation = 17.55%, t = 5.280, p = <0.0001).



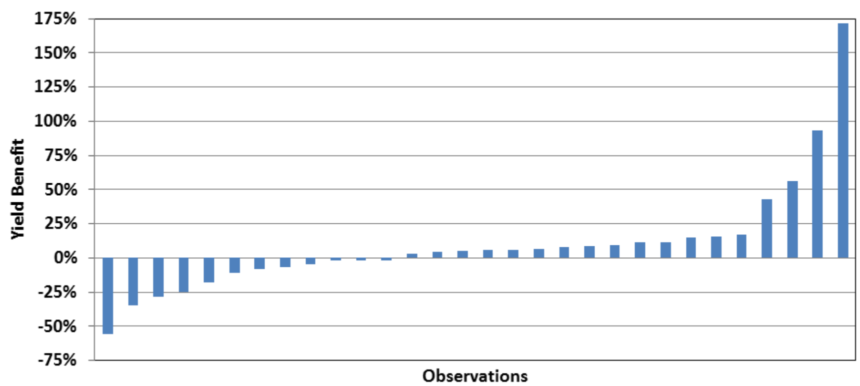
Appendix Figure A2. Sorted bar graph of observed Canadian corn yield benefits for neonicotinoid treatments relative to untreated control treatments (N = 70, minimum = –23.26%, maximum = 93.22%, average = 11.07%, standard deviation = 17.55%, t = 5.280, p = <0.0001).



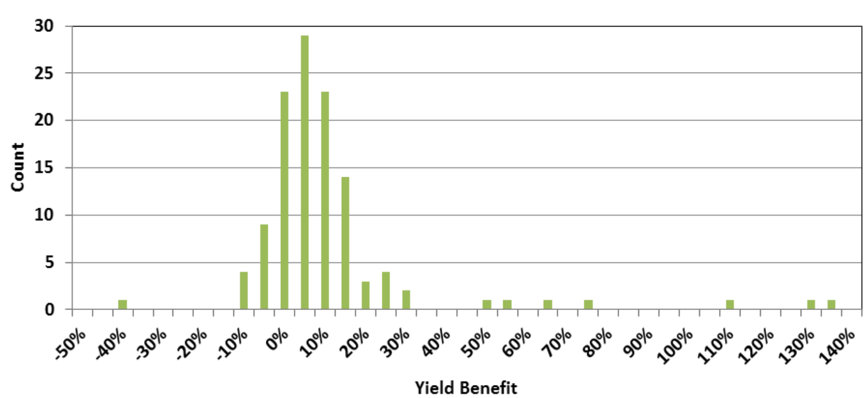
Appendix Figure A3. Histogram of Canadian corn yield benefits for neonicotinoid treatments relative to alternative non-neonicotinoid insecticide treatments (N = 30, minimum = –55.75%, maximum = 171.43%, average = 9.81%, standard deviation = 40.67%, t = 1.321, p = 0.0984).



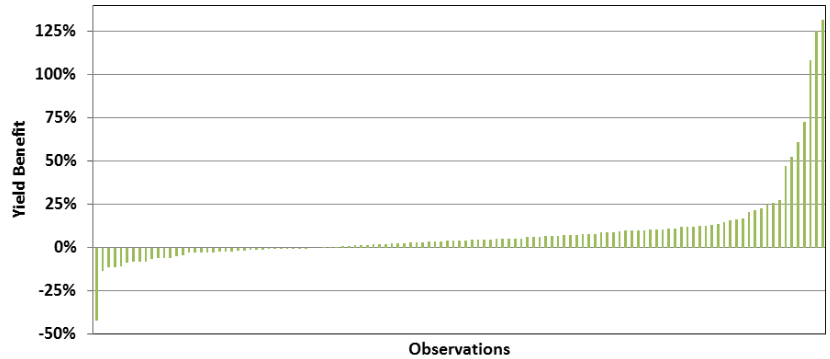
Appendix Figure A4. Sorted bar graph of observed Canadian corn yield benefits for neonicotinoid treatments relative to alternative non-neonicotinoid insecticide treatments (N = 30, minimum = –55.75%, maximum = 171.43%, average = 9.81%, standard deviation = 40.67%, t = 1.321, p = 0.0984).



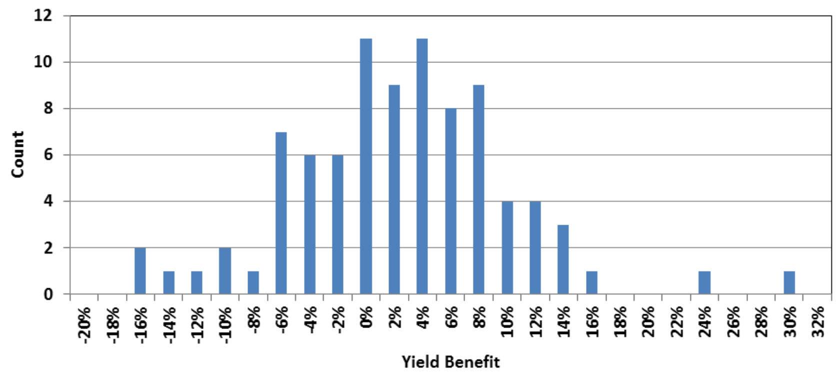
Appendix Figure A5. Histogram of Canadian soybean yield benefits for neonicotinoid treatments relative to untreated control treatments (N = 119, minimum = –42.17%, maximum = 131.82%, average = 8.48%, standard deviation = 22.69%, t = 4.078, p = <0.0001).



Appendix Figure A6. Sorted bar graph of observed Canadian soybean yield benefits for neonicotinoid treatments relative to untreated control treatments (N = 119, minimum = –42.17%, maximum = 131.82%, average = 8.48%, standard deviation = 22.69%, t = 4.078, p = <0.0001).



Appendix Figure A7. Histogram of Canadian soybean yield benefits for neonicotinoid treatments relative to alternative non-neonicotinoid insecticide treatments (N = 88, minimum = –17.36%, maximum = 28.29%, average = 1.56%, standard deviation = 7.86%, t = 1.861, p = 0.0331).



Appendix Figure A8. Sorted bar graph of observed Canadian soybean yield benefits for neonicotinoid treatments relative to alternative non-neonicotinoid insecticide treatments (N = 88, minimum = –17.36%, maximum = 28.29%, average = 1.56%, standard deviation = 7.86%, t = 1.861, p = 0.0331).