AgInfomatics

The Value of Neonicotinoids in North American Agriculture:

A Meta-Analysis Approach to Estimating the Yield Effects of Neonicotinoids

2014

This report series, researched and produced by AgInfomatics, LLC, is a comprehensive analysis of the economic and societal benefits of nitroguanidine neonicotinoid insecticides in North America. The research was sponsored by Bayer CropScience, Syngenta and Valent in support of regulatory review processes in the United States and Canada, with Mitsui providing additional support for the turf and ornamental studies.

AgInfomatics, an agricultural consulting firm established in 1995 by professors from the University of Wisconsin-Madison and Washington State University, conducted independent analyses exploring the answer to the question: *What would happen if neonicotinoids were no longer available?* Comparing that answer to current product use revealed the value of neonicotinoids.

Robust quantitative and qualitative study methods included econometrics modeling of insecticide use, crop yield data and market impacts; surveys of growers, professional applicators and consumers; regional listening panel sessions; and in-depth case studies.

Active ingredients in the study included clothianidin, dinotefuran, imidacloprid and thiamethoxam.

The Value of Neonicotinoids in North American Agriculture

Reports include:

Estimated Impact of Neonicotinoid Insecticides on Pest Management Practices and Costs for U.S. Corn, Soybean, Wheat, Cotton and Sorghum Farmers

Methods and Assumptions for Estimating the Impact of Neonicotinoid Insecticides on Pest Management Practices and Costs for U.S. Corn, Soybean, Wheat, Cotton and Sorghum Farmers

Value of Insect Pest Management to U.S. and Canadian Corn, Soybean and Canola Farmers

A Meta-Analysis Approach to Estimating the Yield Effects of Neonicotinoids

An Economic Assessment of the Benefits of Nitroguanidine Neonicotinoid Insecticides in U.S. Crops

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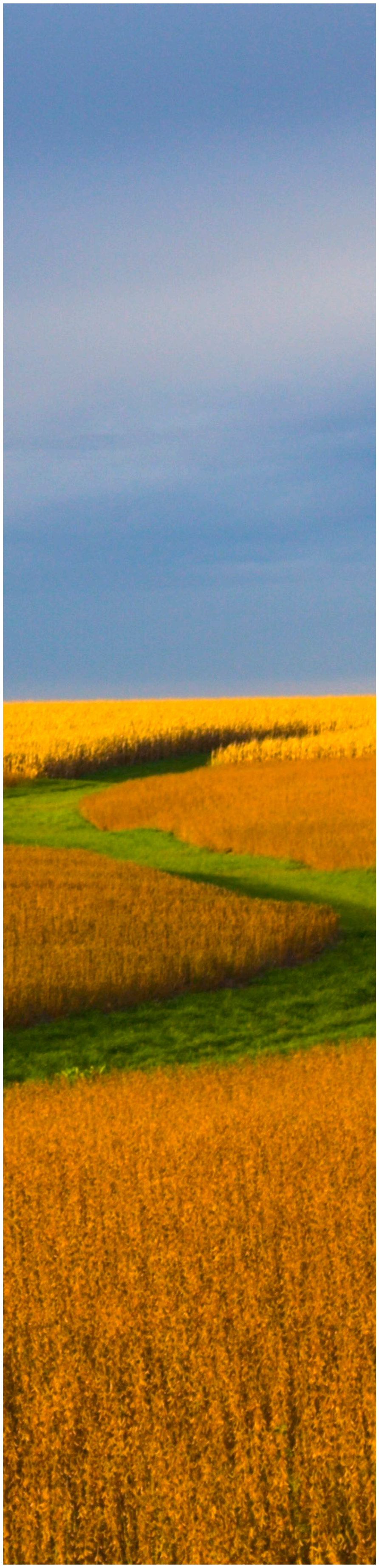

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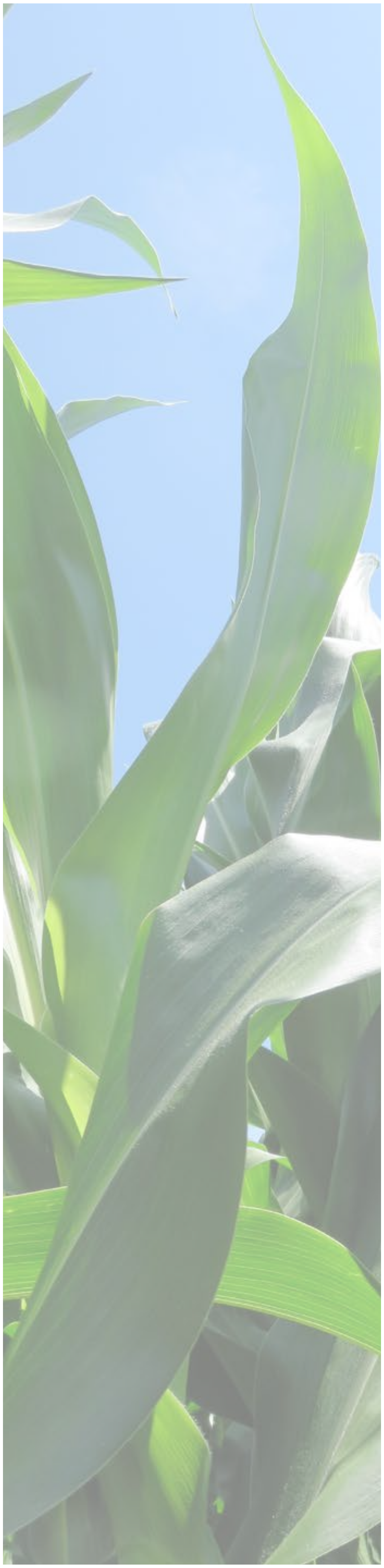
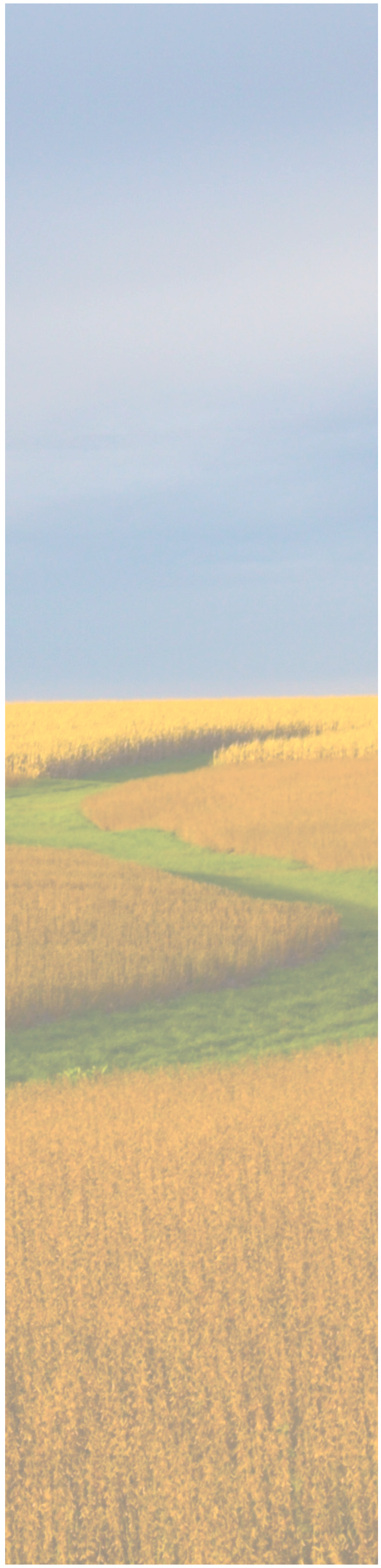
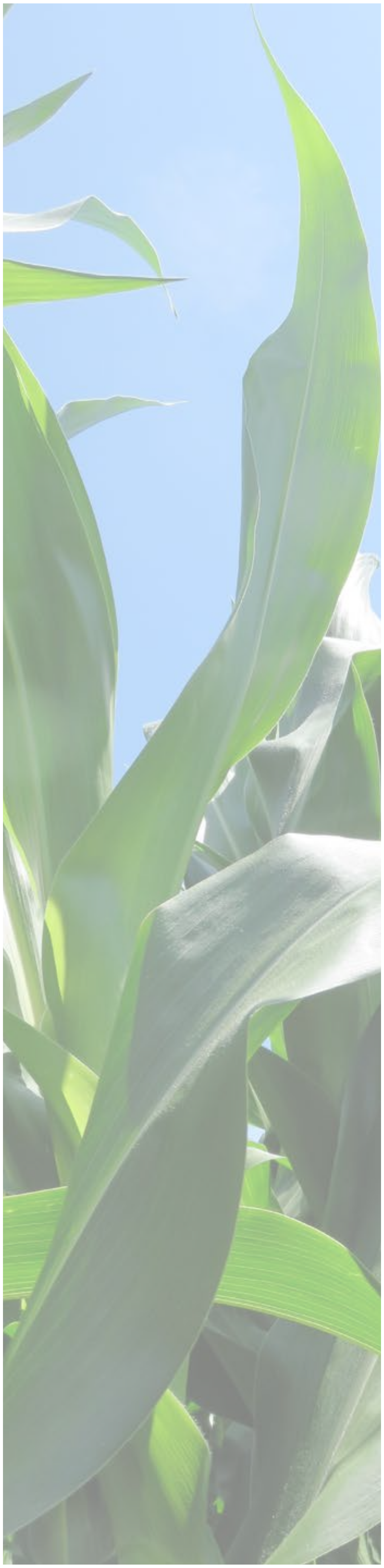




1.0 Introduction

Neonicotinoid insecticides are among the most broadly adopted chemical insecticides used to manage insect pests of annual and perennial crops in the world (Jeschke et al. 2011). The usage data summarized in the report *Estimated Impact of Neonicotinoid Insecticides on Pest Management Practices and Costs for U.S. Corn, Soybean, Wheat, Cotton and Sorghum Farmers* (Mitchell 2014) show that they are the most used insecticide class by U.S. commodity crop farmers. The yield impacts of neonicotinoid insecticides are the primary source of their value, and this report focuses on using existing research data to estimate this yield impact. However, farmers derive other sorts of value from neonicotinoid insecticides beyond the monetary gains implied by increased yields, as examined in the report *Value of Insect Pest Management to U.S. and Canadian Corn, Soybean and Canola Farmers* (Hurley and Mitchell 2014). In addition to controlling pests and increasing yields, the management benefits of neonicotinoids include application flexibility and a diversity of active ingredients with activity against several economically important orders of insect pests (Elbert et al. 2008, Jeschke and Nauen 2008, Jeschke et al. 2011). Further enhancing their adoption in the U.S., the U.S. Environmental Protection Agency (EPA) has classified several neonicotinoids as conventional reduced-risk or organophosphate-alternatives since 2001 (U.S. EPA 2012).

Given their widespread use, many field experiments have examined the impact of neonicotinoids on crop yields in the U.S. and Canada, with some of these studies published in the traditional peer-reviewed scientific literature (e.g., Wilde et al. 1999, 2004, 2007; Knodel et al. 2008; Magalhaes et al. 2009; DeVuyst et al. 2014; Miller et al. 2010) and others only informally published (e.g., Estes et al. 2011, 2012; Rice and Oleson 2004; Smith et al. 2008; DeVries and Wright 2006). Many of these studies are routine efficacy experiments, useful for outreach purposes and generating regulatory data but often difficult to publish in traditional peer-reviewed academic journals. This problem is called 'publication bias' or the 'file drawer problem' and has been a research topic examined in various fields for some time (e.g., Csada et al. 1996, Jennions and Møller 2002, Begg and Mazumdar 1994, Sterne et al. 2001, Madden and Paul 2011).

In entomology, routine studies of this sort tend to be published when scientific interest is high, such as when comparing the efficacy of control methods for invasive pests (e.g., soybean aphid) or to document development of insecticide tolerant or resistant pests (e.g., western corn rootworm). However, much of this insecticide efficacy experimentation goes unreported in peer-reviewed journals and is only documented in extension publications of various sorts (Estes et al. 2011, 2012; Rice and Oleson 2004; Smith et al. 2008; DeVries and Wright 2006). In addition, the Entomological Society of America publishes *Arthropod Management Tests* (AMT), an editor-reviewed publication that contains reports of experiments considered to be routine and potentially not suitable for publication in other scientific journals. Furthermore, registrants also have some of these data, as they often fund field research of this sort to be conducted by faculty and academic staff at universities and by private third party researchers.



Meta-analysis combines existing data from multiple studies to examine a research question (e.g., Paul et al. 2011; Winfree et al. 2009, Madden and Paul 2011). This report uses a meta-analysis approach to assemble data from more than 1,500 field studies to estimate the impact of neonicotinoid insecticides on yield for the following major crops: corn, soybean, wheat, cotton, sorghum, canola, potato and tomato. The primary focus was on the U.S., but data were also gathered for Canada.

A key issue for meta-analysis is to establish clear criteria for inclusion of studies and to appropriately normalize the data from the different studies so that they can be analyzed together. This report describes the meta-analysis approach and results used to estimate the yield effects of neonicotinoid insecticides. First, the **Materials and Methods** section describes the process used to assemble the data and to prepare them for analysis, as well as the methods for statistical analysis used. Next, the **Results** section summarizes the data and presents the results of the analysis. The estimates of the impacts of neonicotinoid insecticides on crop yields reported here serve as a key foundation for the economic assessment of the value of neonicotinoid insecticides described in *An Economic Assessment of the Benefits of Nitroguanidine Neonicotinoid Insecticides in U.S. Crops* (Mitchell and Dong 2014).

2.0 Materials and Methods

The data for this meta-analysis are from three primary sources: 1) published in *Arthropod Management Tests* (AMT), 2) from registrant databases of field experiments they funded to be conducted by faculty and academic staff at universities and a few by private third party researchers and 3) published literature from peer-reviewed journals and other informal reports from university researchers. The first two data sources were chosen because they are relatively standardized databases that contain data collected from studies conducted under standardized field protocols. The third data set was included because key studies were known and it allowed expanding the data for crops with few studies in the first two databases. A few of the studies were in multiple sources because they were reported to the registrants who funded the study but also reported in AMT or other outlets and/or were subsequently used as the basis for peer-reviewed journal articles. As a result, data were carefully examined to remove duplicates.

2.1 Yield response data

Arthropod Management Tests (AMT) is an editor-reviewed publication of the Entomological Society of America (ESA) that reports the results from "preliminary and routine screening for management of arthropods" (http://www.entsoc.org/Pubs/Periodicals/AMT). ESA members can search and access the reports online, but data must be entered by hand into a database. Data were assembled for the following commodity crops: corn, soybean, wheat, cotton, sorghum, canola, potato and tomato. Data were available for these crops for studies conducted from 1996 to 2011 but not for all crops in all of these years. This analysis focused on the nitroguanidine neonicotinoid insecticides imidacloprid, clothianidin, thiamethoxam and dinotefuran, which includes the most widely used neonicotinoid active ingredients in the U.S. and Canada.

For inclusion in this analysis, an AMT study needed to report yield, as well as at least one measure of pest abundance, crop damage or crop health for plots receiving neonicotinoid treatments and untreated control plots. Trade names used to describe insecticide treatments were checked using the Agrian online database (http://www.agrian.com/labelcenter/results.cfm) to ensure that a neonicotinoid insecticide was the only difference between the treated and untreated control. Pertinent information entered for each study site-year included measures of yield, pest control, pest abundance, crop damage and/or crop health for the untreated plots and plots treated with a neonicotinoid insecticide. The number of replicates in the study, standard errors, least significant differences and significance level, and mean square errors of the analysis of variance were entered when available. Additional identifier data from each of the studies was also recorded including: author(s), title, year of the study, location (state and possibly town), crop, pest target(s), insecticide active ingredient, insecticide rate and insecticide application technology (soil applied, seed treatment, foliar applied).

Registrants fund efficacy trials to be conducted by faculty and academic staff at universities and by private third-party researchers. Data from these projects are assembled into databases by registrants, but some of these same data are also published by the researchers in AMT and other outlets. Field trial efficacy data were assembled for these crops from these registrant databases. Just as for the AMT data, to be included in this analysis, a study needed to report yield, plus at least one measure of pest abundance, crop damage or crop health for plots receiving neonicotinoid treatments, and untreated control plots. However, data from studies that included additional treatments were also included. Specifically, studies were included that, in addition to an untreated control and a neonicotinoid treatment, also contained conventional insecticide treatments. Again, when available, the number of replicates for each treatment and the least significant differences for yield for the study were included, as well as identifier data from each of the studies, including researcher(s), project identifier, year of the study, location (state and sometimes town), crop, pest target(s), insecticide active ingredient, insecticide rate, and insecticide application technology (soil-applied, seed treatment, foliar-applied).

In addition, information from published studies for these crops was gathered from the peer-reviewed literature and from various reports from university researchers. However, due to the extent of the data and the time requirements of hand entry, the focus shifted to assembling studies with yield data for plots receiving neonicotinoid treatments and untreated control plots, as well as conventional insecticide treatments. Several studies were included from the peer-reviewed literature (e.g., Wilde et al. 1999, 2004, 2007; Knodel et al. 2008; Magalhaes et al. 2009; DeVuyst et al. 2014; Miller et al. 2010; Royer et al. 2005; Kullik et al. 2011; Soroka et al. 2008), as well as reports from university researchers (e.g., Estes et al. 2011, 2012; Rice and Oleson 2004; Smith et al. 2008; DeVries and Wright 2006). The change in criteria to focus just on yield allowed inclusion of data from agronomic studies (e.g., Gaspar et al. 2014, Esker and Conley 2012; Cox et al. 2007a, 2007b, 2008). Finally, duplicate studies were dropped based on the author, crop, year, available location information and by examining the reported data.

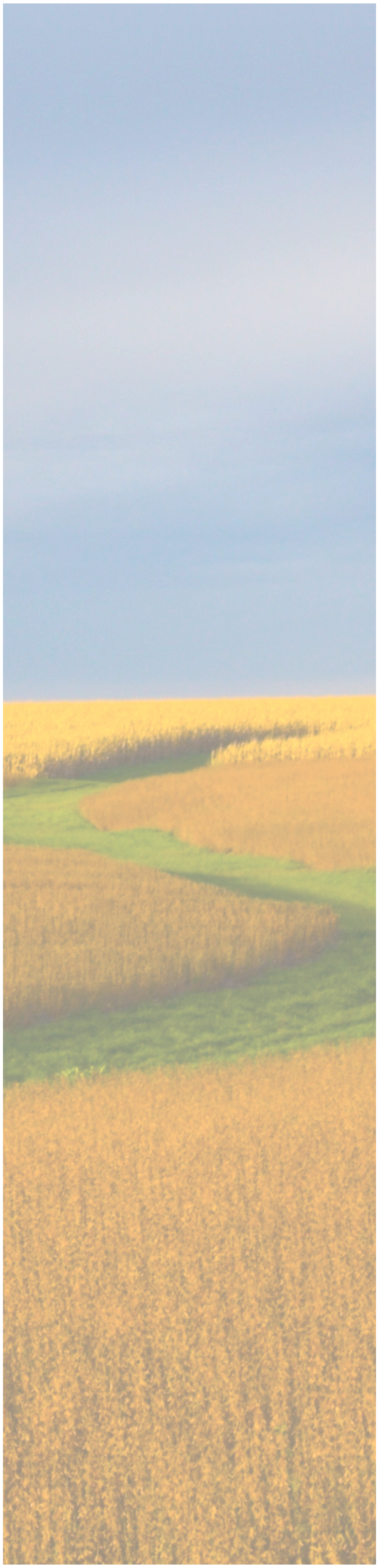


Table 1. Data sources, number of studies and observations by crop for analysis of yields with neonicotinoid insecticides versus untreated control and versus a non-neonicotinoid insecticide.

		Neonicotinoid Insecticide versus Untreated Control		Neonicotinoid versus Non-Neonicotinoid Insecticide	
Crop	**Data Source**	**Studies**	**Observations**	**Studies**	**Observations**
Corn	Publications				
	AMT	25	103	--	--
	Canada	23	77	12	30
	USA	16	176	13	74
	All Publications	64	356	25	104
	Registrant-Funded	250	422	181	328
	Canada	23	77	12	30
	USA	291	701	194	402
	Grand Total	**314**	**778**	**206**	**432**
Soybean	Publications				
	AMT	19	55	--	--
	Canada	9	78	--	--
	USA	19	94	4	11
	All Publications	47	227	4	11
	Registrant-Funded	251	493	117	205
	Canada	9	78		
	USA	289	642	121	216
	Grand Total	**298**	**720**	**121**	**216**
Wheat	Publications				
	AMT	11	75	--	--
	Canada	4	15	2	10
	USA	7	47	2	4
	All Publications	22	137	4	14
	Registrant-Funded	123	260	59	110
	Canada	4	15	2	10
	USA	141	382	61	114
	Grand Total	**145**	**397**	**63**	**124**
	Publications				
	AMT Foliar	23	53	--	--
Cotton	AMT Seed Treatment	45	183	--	--
	Other Publications Foliar	2	6	2	6
	All Publications	70	242	2	6

Continued on next page

Table 1. (continued)

Crop	Data Source	Neonicotinoid Insecticide versus Untreated Control: Studies	Observations	Neonicotinoid versus Non-Neonicotinoid Insecticide: Studies	Observations
	Registrant-Funded				
	Foliar	81	116	76	109
	Seed Treatment	99	180	165	270
	Mixed	170	213	164	206
Cotton (cont'd)	All Registrant Funded	350	509	405	585
	Foliar	106	175	78	115
	Seed Treatment	144	363	165	270
	Mixed	170	213	164	206
	Grand Total	**420**	**751**	**407**	**591**
Canola	Publications				
	AMT	7	17	--	--
	Canada	1	4	--	--
	USA	3	25	2	23
	All Publications	11	46	2	23
	Registrant-Funded	73	132	50	88
	Canada	30	56	30	54
	USA	54	122	22	57
	Grand Total	**84**	**178**	**52**	**111**
Sorghum	Publications				
	AMT	1	4	--	--
	Other Publications	5	23	--	--
	All Publications	6	27	--	--
	Registrant-Funded	67	135	43	77
	Grand Total	**73**	**162**	**43**	**77**
Potato	Publications				
	AMT	21	41	--	--
	All Publications	21	41	--	--
	Registrant-Funded	173	269	63	109
	Grand Total	**194**	**310**	**63**	**109**
Tomato	Publications				
	AMT (Fresh)	22	63	--	--
	Grand Total	**22**	**63**	--	--
All crops	**Grand Total**	**1,550**	**3,359**	**995**	**1,660**

Table 1 summarizes the data used for this analysis by crop and source. A single study may have multiple treatments at multiple site-years. For example, a study may have for each site-year an untreated control, plus three different neonicotinoid seed treatments (i.e., clothianidin, imidacloprid and thiamethoxam), plus different non-neonicotinoid insecticides. Furthermore, a single study may contain data from multiple locations and for multiple years (i.e., multiple site-years). As a result, the number of observations for analysis exceeds the number of studies. In total for these eight crops, data from a total of 1,550 studies were assembled, generating 3,359 observations of yield for both a neonicotinoid insecticide treatment and an untreated control. In addition, data from a total of 955 studies were assembled, generating 1,611 observations of yield for both a neonicotinoid insecticide treatment and a non-neonicotinoid insecticide treatment.

Totals from Table 1 indicate that data was from 174 studies published in AMT for these crops, plus 89 publications in journals and other miscellaneous publications. An appendix of references includes many of these. The registrant funded studies are not cited unless they were also published in other sources, in which case the other source is cited and the duplicate study in the database of registrant funded studies was deleted.

Totals from Table 1 also indicate that about one-third of the observations for neonicotinoid yields compared to untreated control treatments are from AMT and other publications, while the remaining observations are from registrant databases for studies conducted by faculty and academic staff at universities and by a few third party researchers. Among corn, soybean, wheat, cotton and canola, the percentages from publications range from a low of 31.5 percent for soybean to a high of 45.8 percent for corn. The extremes are 13.2 percent and 16.7 percent of the observations from publications for sorghum and potato and a high of 100 percent for tomato. For neonicotinoid yields compared to untreated control treatments, observations from publications constitute about 10 percent of the observations, with data from registrant databases constituting the remaining observations. This occurred because the AMT data for non-neonicotinoid insecticides were not included in the initial data entry process.

As expected, more observations are from the U.S. than Canada. For neonicotinoid yields compared to untreated control treatments, Table 1 shows that all the observations are from the U.S. for cotton, sorghum, potato and tomato. For the remaining crops, about 10 percent of the soybean and corn observations are from Canada, while not quite 7 percent of the canola observations and less than 4 percent of the wheat observations are from Canada. For neonicotinoid yields compared to non-neonicotinoid insecticide treatments, these percentages remain about the same, with observations from Canada not exceeding 10 percent of the observations for any one crop.

Finally, though not reported, across these crops, observations for imidacloprid constitute about 45 percent of the observations for neonicotinoid yields compared to untreated control treatments, which is not surprising since it is the first neonicotinoid insecticide registered for use in the U.S and Canada. Observations for thiamethoxam constitute about 36 percent of the observations, while observations for clothianidin constitute about 18 percent of the observations, with dinotefuran and mixtures of neonicotinoid active ingredients constituting less than 2 percent of the observations. The percentages of observations for each neonicotinoid active ingredient remain almost the same for neonicotinoid yields compared to non-neonicotinoid insecticide treatments.

2.2 Yield response variables

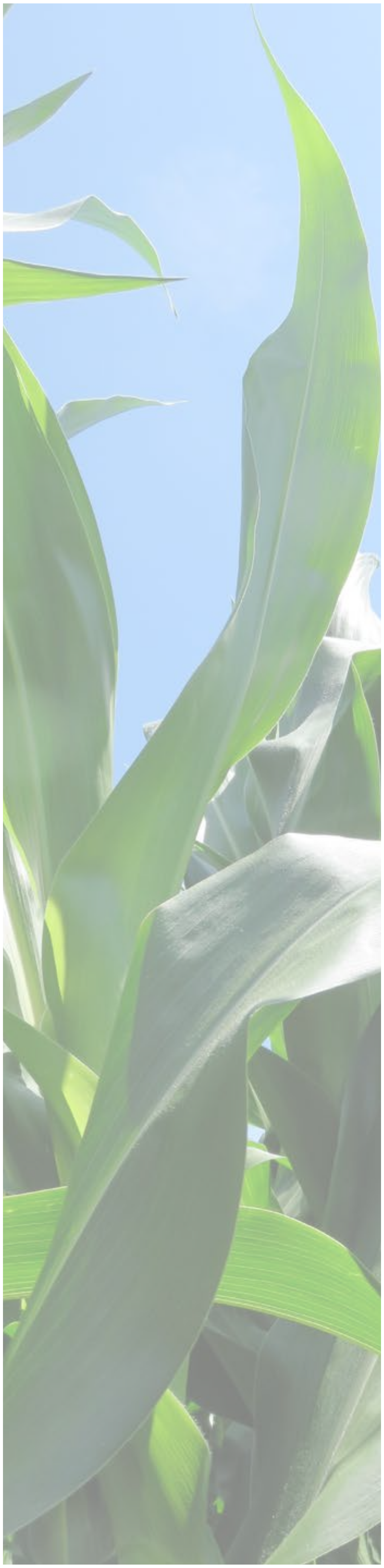
For this meta-analysis, crop yield for each insecticide treatment at a study site-year is the response variable of interest. If multiple treatments were available for the same insecticide active ingredient for a study site-year, yields were averaged across these treatments. For example, if a study included different rates or different formulations for the same neonicotinoid active ingredient, the average yield for these treatments was used. As a result for each site-year, a study could generate at most four neonicotinoid observations – one each for clothianidin, dinotefuran, imidacloprid and thiamethoxam. Similarly, since the focus is on neonicotinoids, yield was averaged across all non-neonicotinoid insecticide treatments at a study site-year to generate at most one yield observation for all non-neonicotinoid insecticide treatments if a study included such treatments. Thus, the final data for each study site-year included three types of yields: 1) yield for the untreated control, 2) up to four neonicotinoid yields, one for each active ingredient, and 3) possibly a non-neonicotinoid insecticide yield. Also, note that the insecticide active ingredients are not differentiated, except as neonicotinoid and non-neonicotinoid.

To allow comparison across different studies, the yield observations from each study were normalized to eliminate any direct effects of the environment or geographic location on yield. Two types of yield comparisons are examined in this meta-analysis: 1) the yield impact of the neonicotinoid insecticide relative to no insecticide treatment and 2) the yield impact of the neonicotinoid insecticide relative to a non-neonicotinoid insecticide treatment. If the neonicotinoid and non-neonicotinoid insecticide treatments only included insecticides, then the base used was the untreated control, but if the insecticide treated plots also included fungicides, then the base used was the fungicide only treatment.

Based on these yields for each study site-year, measures of the neonicotinoid yield impact are calculated as the percentage change relative to the appropriate case. Specifically, the yield impact of a neonicotinoid insecticide treatment relative to no insecticide treatment is the net percentage increase in yield, calculated for each crop $\boldsymbol{i}$ for study site-year $\boldsymbol{j}$ as:

$$\%\Delta_{ij}^{Nvs0} = \frac{Y_{ij}^{NNi} - Y_{ij}^{UTC}}{Y_{ij}^{UTC}} \times 100 \tag{1}$$

Here $\boldsymbol{Y}$ denotes yield, the superscripts $\boldsymbol{NNi}$ and $\boldsymbol{UTC}$ respectively denote the neonicotinoid treated and untreated control, and the superscript $\boldsymbol{Nvs}0$ on $\%\Delta$ denotes that the percentage change for the neonicotinoid yield is expressed relative to the yield for the untreated control. For example, if the measured neonicotinoid and untreated control yields were 105 and 100, then $\%\Delta_{ij}^{Nvs0}$ = ((105 – 100)/100) x 100 = 5%, implying that the neonicotinoid treated yield was 5 percent larger than the untreated control yield for crop $\boldsymbol{i}$ and study site-year $\boldsymbol{j}$. Note that this percentage change is negative if the yield with the neonicotinoid treatment is less than the yield



with the untreated control. This yield impact metric is invariant to the units of measure used and so can be compared across studies and across crops.

In addition to an untreated control, some studies also included treatments using insecticides other than neonicotinoids. For these studies, the yield impact of a neonicotinoid insecticide treatment relative to a non-neonicotinoid insecticide treatment is the net percentage increase in yield, calculated for each crop ***i*** for study site-year ***j*** as:

$$\%\Delta_{ij}^{NvsI} = \frac{Y_{ij}^{NNi} - Y_{ij}^{Ins}}{Y_{ij}^{Ins}} \times 100 \tag{2}$$

Here the superscript ***Ins*** denotes a non-neonicotinoid insecticide, and the superscript ***NvsI*** on %Δ denotes that the percentage change for the neonicotinoid yield is expressed relative to the yield with a non-neonicotinoid insecticide. For example, if the measured yields for the neonicotinoid insecticide and non-neonicotinoid insecticide treatments were respectively 103 and 100, respectively, then $\%\Delta_{ij}^{NvsI}$ = ((103 – 100)/100) x 100 = 3%, implying that the yield with a neonicotinoid was 3 percent larger than yield with a non-neonicotinoid insecticide for crop ***i*** and study site-year ***j***. Again, this percentage change is negative if the yield with the neonicotinoid treatment is less than the yield with the insecticide treatment, and this yield impact metric is invariant to the units of measure used and so can be compared across studies and across crops.

The yield response ratio is an alternative measure used here for statistical analysis of the yield benefit of neonicotinoid treatments relative to untreated control treatments and to non-neonicotinoid insecticide treatments. The response ratio is closely tied to the percentage change but has improved statistical properties (Hedges et al. 1999). The response ratio is the ratio of the treated to the untreated yield. For example, if the measured neonicotinoid and untreated control yields were 105 and 100, respectively, then the yield response ratio would be 105/100 = 1.05. Thus, the response ratio is a transformation of the percentage changes defined by equation (1) and (2). The natural logarithm of the response ratio is used to reduce the impact of skewness and to give an approximately normal distribution for statistical analysis (Hedges et al. 1999).

The natural logarithm of the response ratio for the yield impact of a neonicotinoid insecticide treatment relative to no insecticide treatment is calculated for each crop ***i*** for study site-year ***j*** as:

$$\ln(RR_{ij}^{Nvs0}) = \ln\left(\frac{Y_{ij}^{NNi}}{Y_{ij}^{UTC}}\right) = \ln\left(\frac{\%\Delta_{ij}^{Nvs0}}{100} + 1\right) \tag{3}$$

Similarly, the natural logarithm of the response ratio for the yield impact of a neonicotinoid insecticide treatment relative to a non-neonicotinoid insecticide treatment is calculated for each crop ***i*** for study site-year ***j*** as:

$$\ln(RR_{ij}^{NvsI}) = \ln\left(\frac{Y_{ij}^{NNi}}{Y_{ij}^{Ins}}\right) = \ln\left(\frac{\%\Delta_{ij}^{NvsI}}{100} + 1\right) \tag{4}$$

These two measures are used to test for the statistical significance of the observed average yield benefit of neonicotinoid insecticides.

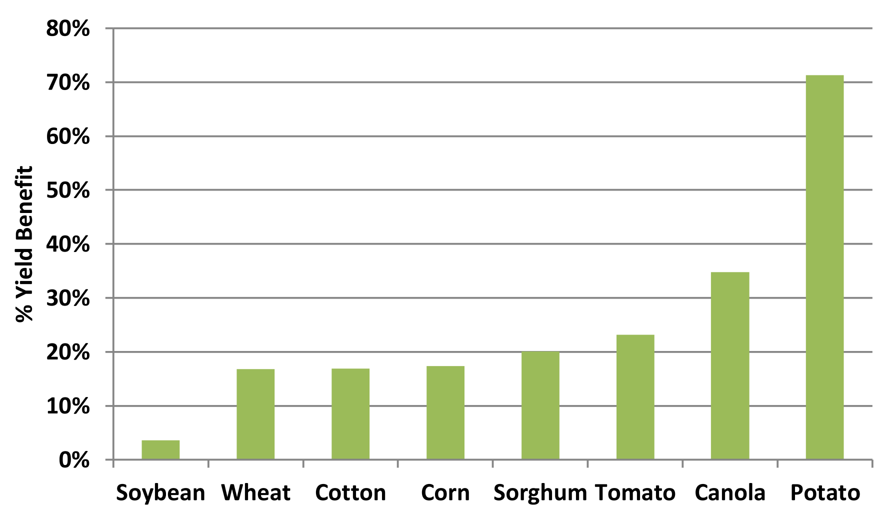
3.0 Results

Results are reported both numerically and graphically for each crop. Tables 2 and 3 and Figures 1 and 2 report the main results for each crop, while an appendix provides multiple tables and figures for each crop to report more detailed and comprehensive results. The discussion here focuses on the main results – the average yield benefit for neonicotinoid insecticide treatments relative to untreated control treatments and to non-neonicotinoid treatments for the eight crops: corn, soybean, wheat, cotton, canola, sorghum, potato and tomato.

Table 2 reports the average yield benefit of neonicotinoid treatments compared to untreated control treatments by crop, while Table 3 reports the average yield benefit of neonicotinoid treatments compared to non-neonicotinoid insecticide treatments. Not only are averages reported for all observations for a crop but also for different sub-categories (for observations from published studies and from registrant-funded studies, and for observations from U.S. and from Canadian locations). Also, p values are reported from one-sided t tests of the sign of the observed average benefit. For example, if the observed yield benefit is positive, the null hypothesis is that the average benefit is negative. For the null hypothesis that the observed average benefit is zero, p values would be two times larger than those reported in Tables 2 and 3.

Average benefits reported in Tables 2 and 3 are shown after dropping as outliers any observation more than six standard deviations from the mean. Therefore, the number of observations is also reported in Tables 2 and 3 and can differ from those reported in Table 1. For example, Table 1 lists 778 observations for corn, while Table 2 lists 774 because 4 observations were dropped as outliers based on the six-sigma criterion. The six-sigma criterion was inadequate for canola yields comparing neonicotinoid treatments to untreated control treatments. Because of some extreme observations, the six-sigma criterion would have dropped all observations exceeding 6,894 percent, much higher than for any other crop. As a result, a judgment was made to drop 8

Figure 1. Average yield benefit by crop for neonicotinoid insecticide treatments relative to untreated control treatments (using all data, see Table 2 for p values).



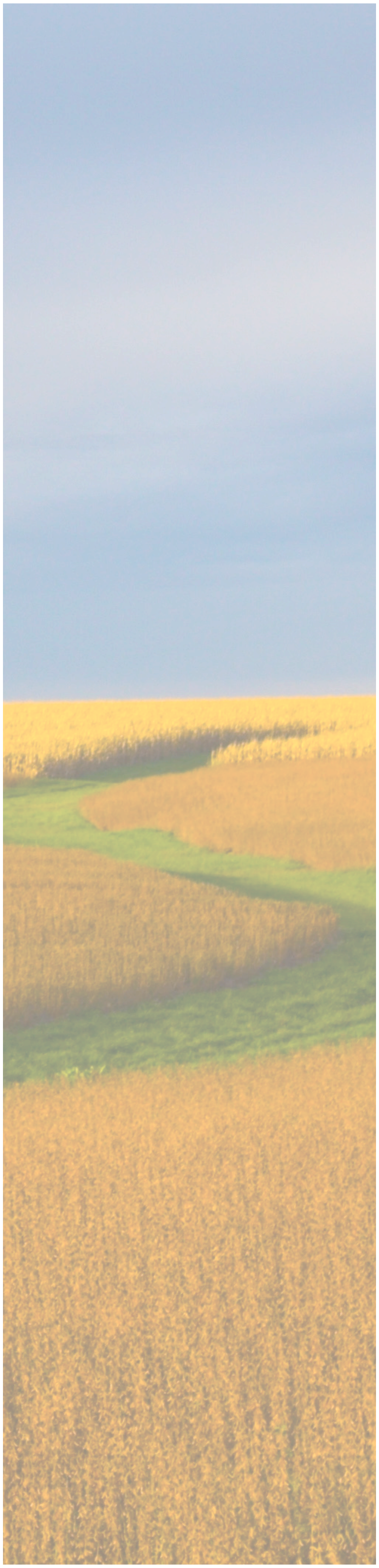


Table 2. Average yield benefit by crop for neonicotinoid insecticide treatments relative to untreated control treatments.

Crop	Category	Obs.	Average Yield Benefit (%)	p Value (one-sided t test of sign*)	
				Yield Benefit	ln (Response Ratio)
Corn	Publications	356	14.0%	<0.0001	<0.0001
	Registrant-Funded	418	20.3%	<0.0001	<0.0001
	Canada	77	13.2%	<0.0001	<0.0001
	USA	697	17.8%	<0.0001	<0.0001
	All	**774**	**17.4%**	**<0.0001**	**<0.0001**
Soybean	Publications	225	5.5%	<0.0001	<0.0001
	Registrant-Funded	493	2.7%	<0.0001	0.0012
	Canada	76	10.2%	0.0002	0.0002
	USA	642	2.8%	<0.0001	<0.0001
	All	**718**	**3.6%**	**<0.0001**	**<0.0001**
Wheat	Publications	136	17.1%	<0.0001	<0.0001
	Registrant-Funded	260	16.6%	<0.0001	<0.0001
	Canada	15	41.7%	0.0009	0.0003
	USA	381	15.8%	<0.0001	<0.0001
	All	**396**	**16.8%**	**<0.0001**	**<0.0001**
Cotton	Publications	241	20.6%	<0.0001	<0.0001
	Registrant-Funded	505	15.1%	<0.0001	<0.0001
	Foliar	173	16.9%	<0.0001	<0.0001
	Seed Treatment	362	17.2%	<0.0001	<0.0001
	Mixed	211	16.4%	<0.0001	<0.0001
	All	**746**	**16.9%**	**<0.0001**	**<0.0001**
Canola	Publications	46	42.0%	<0.0001	<0.0001
	Registrant-Funded	132	32.2%	<0.0001	<0.0001
	Canada	56	30.5%	<0.0001	<0.0001
	USA	122	36.7%	<0.0001	<0.0001
	All	**178**	**34.8%**	**<0.0001**	**<0.0001**
Sorghum	Publications	27	5.3%	0.1362	0.3230
	Registrant-Funded	135	23.1%	<0.0001	<0.0001
	All	**162**	**20.1%**	**<0.0001**	**<0.0001**
Potato	Publications	41	59.9%	<0.0001	<0.0001
	Registrant-Funded	265	73.1%	<0.0001	<0.0001
	All	**306**	**71.3%**	**<0.0001**	**<0.0001**
Tomato	Publications	63	23.2%	<0.0001	<0.0001
	All	**63**	**23.2%**	**<0.0001**	**<0.0001**

*One-sided t-test of the null hypothesis that the yield benefit has the opposite sign of the average yield benefit, based on the untransformed percentage yield benefit or the natural logarithm of the response ratio for the yield benefit.

Table 3. Average yield benefit by crop for neonicotinoid insecticide treatments relative to non-neonicotinoid insecticide treatments.

Crop	Category	Obs.	Average Yield Benefit (%)	p Value (one-sided t test of sign*)	
				Yield Benefit	ln (Response Ratio)
Corn	Publications	104	2.8%	0.1177	0.3639
	Registrant-Funded	325	4.9%	<0.0001	<0.0001
	Canada	30	9.8%	0.0984	0.2412
	USA	399	4.0%	<0.0001	0.0001
	All	**429**	**4.4%**	**<0.0001**	**0.0002**
Soybean	Publications	11	3.3%	0.0621	0.0687
	Registrant-Funded	205	0.0%	0.4812	0.2791
	Canada	--	--	--	--
	USA	216	0.2%	0.3735	0.3746
	All	**216**	**0.2%**	**0.3735**	**0.3746**
Wheat	Publications	14	4.1%	0.0186	0.0210
	Registrant-Funded	108	2.2%	0.0274	0.0621
	Canada	10	4.3%	0.0417	0.0461
	USA	112	2.3%	0.0214	0.0496
	All	**122**	**2.4%**	**0.0099**	**0.0247**
Cotton	Publications	6	-2.6%	0.0527	0.0519
	Registrant-Funded	585	0.7%	0.0411	0.2837
	Foliar	115	2.2%	0.0223	0.0580
	Seed Treatment	270	0.4%	0.2572	0.4630
	Mixed	206	0.3%	0.3459	0.3741
	All	**591**	**0.7%**	**0.0472**	**0.3071**
Canola	Publications	23	4.5%	0.3436	0.2283
	Registrant-Funded	88	11.1%	0.0083	0.0788
	Canada	54	18.9%	0.0033	0.0152
	USA	57	0.9%	0.4273	0.1281
	All	**111**	**9.7%**	**0.0119**	**0.3111**
Sorghum	**All****	**77**	**5.9%**	**0.0062**	**0.0109**
Potato	**All****	**109**	**12.6%**	**<0.0001**	**<0.0001**
Tomato	--	--	--	--	--

*One-sided t-test of the null hypothesis that the yield benefit has the opposite sign of the average yield benefit, based on the untransformed percentage yield benefit or the natural logarithm of the response ratio for the yield benefit.
**All observations from registrant-funded studies conducted in the U.S.

observations with yield benefits ranging from 366 percent to 13,288 percent, leaving a maximum observed yield benefit of 267 percent, which was in the range of the maximums observed for the other crops.

Figures 1 and 2 report the average yield benefits from Tables 2 and 3 by crop using all observations. As a result, these figures provide no new information but quickly show the main results and indicate the relative magnitudes of the yield benefits across these crops.

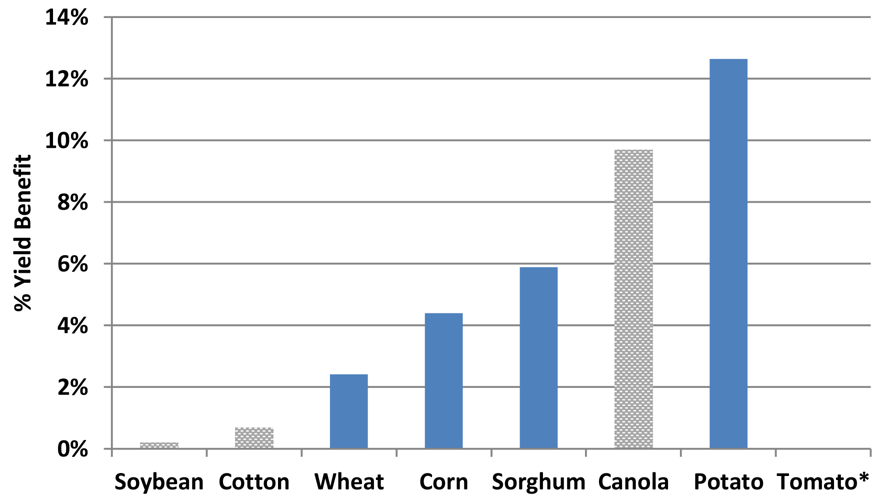
3.1 Main findings

Table 2 and Figure 1 indicate substantial yield benefits for neonicotinoid insecticides relative to untreated control treatments. This result is not surprising, since widely used insecticides would almost certainly be efficacious and generate yield benefits, otherwise the demand would collapse. Furthermore, efficacy trials are part of the registration process. The average yield benefit ranges from 3.6 percent for soybeans to 71.3 percent for potato – all statistically significant based on the reported results for both t tests. The yield benefit for soybean is noticeably lower and the benefit for potato noticeably higher than for the other crops. Yield benefits for the commodity crops of corn, wheat and cotton are about 17 percent and reach 20 percent for sorghum. For specialty crops, the yield benefit is 23 percent for (fresh) tomatoes. As a commodity crop, canola has a large benefit of almost 35 percent. Based on these results, neonicotinoid insecticides generate substantial yield benefits.

Given typical yields and crop prices, these yield benefits are more than enough to pay for the typical cost of a neonicotinoid insecticide treatment in these crops, including soybean. For example, using the 2013 U.S. average soybean yield of 44 bu/A and the marketing year average price of $13/bu (USDA-NASS 2014), a 3.6 percent average yield benefit implies a gain of $20.59/A, more than enough to earn back the cost of the neonicotinoid seed treatment, which averaged $7.67/A from 2010-2012 (p. 56, Mitchell 2014). Even using the 2.8 percent yield benefit for the U.S. observations gives the same general results – an expected gain of $16.02/A, more than enough to earn back the cost of the neonicotinoid seed treatment and bring significant revenue to the grower. The same general results will hold for the other crops as well, based on U.S. average prices and yields and the average yield benefits in Table 2.

Table 2 also reports the average yield benefit separately for observations from publications and from registrant funded studies. Differences are evident, but the differences are not systematic. For corn, observations from registrant-funded studies have an average benefit of 20 percent, but the average benefit is only 14 percent for observations from publications. However, the difference is reversed for soybean, observations from registrant-funded studies have an average yield benefit of 2.7 percent, while observation from publications have an average yield benefit of 5.5 percent. Both averages are very similar for wheat, 17.1 percent and 16.6 percent. For cotton and canola, the average yield benefit for observations from publications is noticeably larger than from registrant funded studies, while the opposite occurs for sorghum and potato. Based on this lack of any systematic difference, it seems appropriate to combine the data sets and not

Figure 2. Average yield benefit by crop for neonicotinoid insecticide treatments relative to non-neonicotinoid insecticide treatments (using all data, see Table 3 for p values; insignificant average (p > 0.05) in hatched gray). *No data for Tomato.

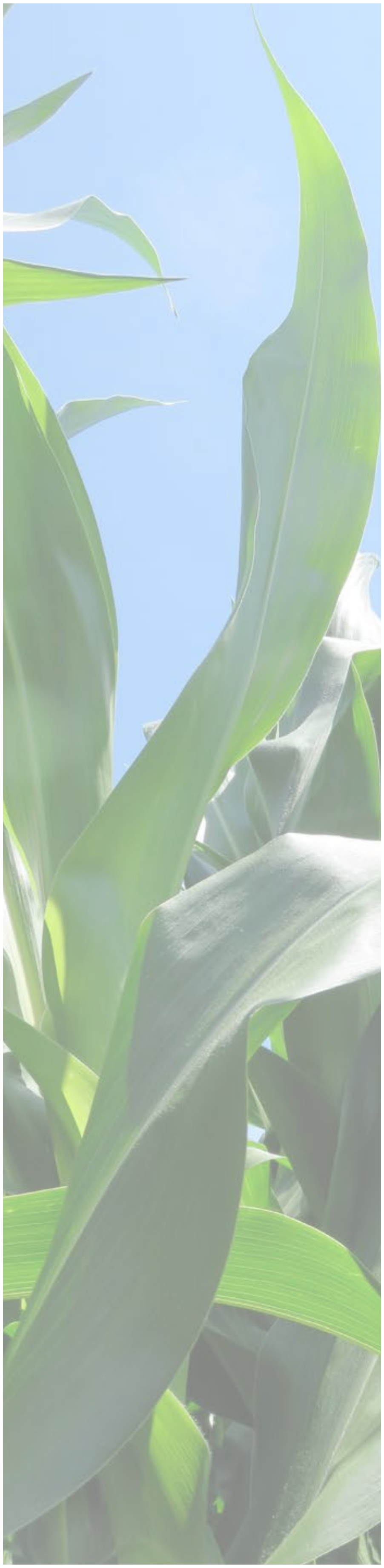


to distinguish among the sources. This result is not surprising since these studies are conducted under standard scientific protocols regardless of the funding source, so that any differences evident in Table 2 are likely due to sampling error.

In general, the data contain fewer observations from Canadian locations, ranging from 3.8 percent of the observations for wheat to 31.5 percent for canola and about 10 percent of the corn and soybean observations. For corn, the average benefit for the Canadian observations is lower than for the U.S. observations (13.2 percent versus 17.8 percent), which also occurs for canola (30.5 percent versus 36.7 percent), while for soybean, the average benefit for the Canadian observations is greater than for the U.S. observations (10.2 percent versus 2.8 percent). These differences are likely due to differences in the pest populations and in the spectrum of pests in the different regions, as well as sampling error.

Finally, it is important to note that these yield benefits are averages, not certain outcomes, with actual yield outcomes varying across years based on weather and insect pressure, and these averages also vary geographically. The appendix of results provides histograms and other plots to show the variability in the yield benefit across all the data, plus tables and figures showing how the average varies across states.

Table 3 and Figure 2 indicate smaller yield benefits for neonicotinoid insecticides relative to non-neonicotinoid treatments than was the case relative to untreated control treatments. This result is not surprising, since the insecticide market is well-established, generally with multiple active ingredients available that must demonstrate of efficacy against at least some of the main insect pests to be registered for use in a crop and to gain market acceptance. Furthermore, most of the neonicotinoid insecticides are applied as seed treatments or in the furrow at the time of planting, while for many studies, the non-neonicotinoid insecticides were applied as foliar applications later in the season. As a result, some of the differences in observed yield benefits are due to differences in the application method and time of application as they relate to incidence of pest pressure, not just the insecticide used.



For soybean and cotton, the average yield benefits in Table 3 are quite small and not statistically significant based on the reported p values. The observed 2.4 percent average yield benefit for wheat is statistically significant based on both p values, as is the 4.4 percent average benefit for corn, the 5.9 percent average benefit for sorghum and the 12.6 percent average benefit for potato. The average benefit for canola is significant using the p value for the untransformed percentage yield benefit but much larger and not significant based on the p value for the log-transformed response ratio. The large difference between these two p values implies skewness, and non-normality is likely an issue, which the log-transformation is intended to correct or improve, and the p value for the log-transformed response ratio is used to indicate statistical significance in Figure 2. The implication is that though the average yield benefit is large at 9.7 percent; it is also highly variable. In some field experiments, a neonicotinoid seed treatment provided excellent control of target pests, noticeably outperforming a foliar-applied insecticide, while in other field experiments, the reverse occurred.

Table 3 also reports the average yield benefit separately for observations from publications and from registrant funded studies, and just as in Table 2, differences are evident, but the differences are not systematic. For corn, cotton and canola, the average yield benefit for observations from registrant funded studies is greater than for observations from publications, while for soybean and wheat, the opposite occurs. Again, because these studies are conducted under standard scientific protocols, regardless of the employer or funding source, this result is not surprising. Therefore, it seems appropriate to combine the data sets and not distinguish among the sources.

The data comparing yields with neonicotinoid treatments to non-neonicotinoid insecticide treatments contain few observations from Canadian locations – none for soybean and around 7 percent to 8 percent for corn and wheat. Canola is the exception, with almost half of the observations used in this study originating from Canada. For both corn and wheat, the average yield benefit for the Canadian observations is about twice as large as for the U.S. observations. While for canola, the average yield benefit for the Canadian observations is almost 19 percent, the yield benefit was not even 1 percent from U.S. observations. This same trend was also evident for soybean and wheat in Table 2 but not for corn and canola. Again, these differences are likely due to differences in the pest populations and in the spectrum of pests in the different regions, as well as sampling error.

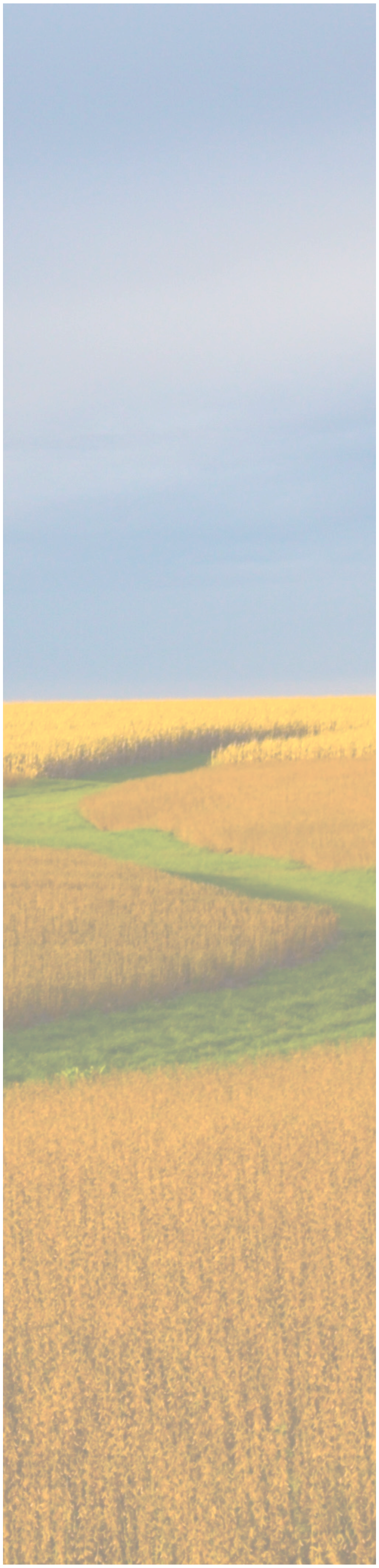
4.0 Caveats and Discussion

Several caveats and qualifications apply to these averages and other estimates reported here. This analysis is based on small plot data, and such results do not necessarily directly translate to the same performance at the field level. In some sense, a field is an aggregation of many small plots and so will have less variability in treatment effects than occurs in small plots, but other effects and sources of variability can appear.

These meta-analysis averages across all observations collected from multiple site-years, but results depend on the locations where plots were established, the pest pressure that occurred, and the treatments examined. If a study were conducted in a location where few target pests appear, it would not be surprising if the insecticide treatment did not have a significant effect on crop yield – there was no pest to control. On the other hand, some studies use methods to ensure a high pest population, such as trap crops planted the previous season; so that if the insecticide is efficacious, it is not surprising to see a significant yield difference. Controlling the yield analysis with measures of insect control, crop damage and crop health is one approach to address this issue (i.e., regressing the yield benefit on these measures), but such an approach would require assembling more information from the numerous studies. Furthermore, such an analysis would estimate the expected yield benefit under different levels of control or pest pressure but would not indicate what level of pest pressure or control to use. Using the average pest pressure or control from the data and applying the regression model would give the averages of the yield benefit, which is essentially what is reported here.

The averaging of yield benefits across site-years can also be weighted, for example, by the number of replicates or by some measure of variability at that site-year. Again, such an approach would require assembling more information from the numerous studies. Weighting methods based on the number of replicates would likely not give results substantially different than reported here; there is generally little variation in the number of replicates across small plot field studies, with most using 3 or 4 replicates. Weighting methods based on measure of site-year yield variability could give different results than reported here; many of the observations would be dropped as no yield variably information is reported, plus there is noticeable variation in measured yield variability across site-years.

Despite these various caveats, this analysis provides useful estimates of the average yield benefit to expect for neonicotinoid insecticides for these crops across the U.S. and Canada. These averages will be used for a highly aggregated market-level analysis of the economic benefits of neonicotinoids reported in *An Economic Assessment of the Benefits of Nitroguanidine Neonicotinoid Insecticides in U.S. Crops* (Mitchell and Dong 2014). Finally, note that the analysis summarized here focuses solely on the yield benefits of neonicotinoid insecticides. However, these insecticides and their commonly used application method via seed treatment also generate a variety of non-monetary benefits for farmers that are not accounted for by just the yield benefit. For example, benefits such as resistance management, better targeting of insecticides so that additional pest control from beneficial insects is not lost, and increased convenience and safety. The value of these and similar benefits to farmers are estimated in the report *Value of Insect Pest Management to U.S. and Canadian Corn, Soybean and Canola Farmers* (Hurley and Mitchell 2014).



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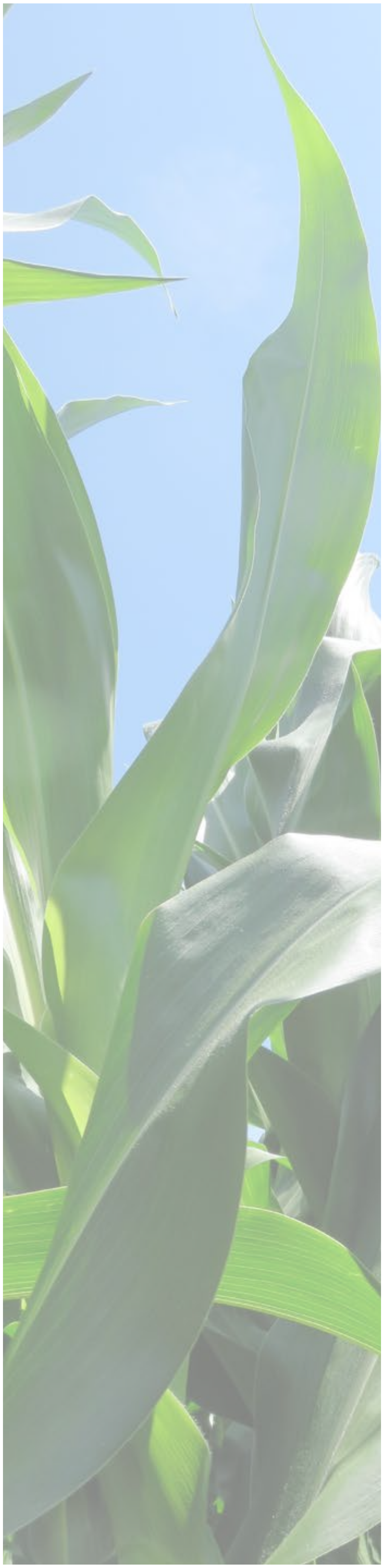
6.0 Appendix of Results

This appendix presents a standard set of four tables and six figures for each crop. The key data are reported and discussed in the main text of this report, but some of the supporting data are reported in this appendix, in particular, more detailed data on state/province specific results. This introductory text briefly explains the standard set of tables and figures that is presented for each crop, which is slightly modified for sorghum and tomato due to sparse data.

The first two tables for each crop report various summary data for different sub-categories of the sources, including publications, registrant-funded studies or studies conducted in Canada and in the U.S. The data reported includes the number of studies and observations, the average and standard deviation of the yield benefit, plus the associated t statistic and p value for the one-side t test of the null hypothesis that the yield benefit has the opposite sign as the observed average yield benefit. Crop Table 1 reports this information for the yield benefit of neonicotinoid treatments relative to untreated control treatments, while Crop Table 2 does the same for the yield benefit of neonicotinoid treatments relative to non-neonicotinoid insecticide treatments. Crop Tables 3 and 4 report the same information, but by state, to give some indication of the geographic variability of the yield benefit.

After these tables, a series of six figures is presented. Crop Figure 1 is a histogram of the yield benefit for the neonicotinoid treatments relative to untreated control treatments to indicate the general statistical distribution of this yield benefit, while Crop Figure 2 sorts the observed yield benefits and then plots them as bar graphs to show all the data visually. Crop Figures 3 and 4 are the same data plots, but for the yield benefit for the neonicotinoid treatments relative to non-neonicotinoid insecticide treatments. For these four figures, the legends report the number of observations, as well as the minimum, maximum, average and standard deviation. Finally to make the regional differences more visually apparent, Crop Figures 5 and 6 show the average yield benefits by state from Crop Tables 3 and 4.

Note that in these tables, t statistics and p values are reported. These are for one-sided t tests of the null hypothesis that the yield benefit has the opposite sign as the observed average yield benefit.



Corn Table 1. Sample statistics for the corn yield benefit by data source for neonicotinoid treatments relative to untreated control treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT	25	103	26.9%*	42.4%	6.440	<0.0001
Publications Canada	23	77	13.2%*	27.5%	4.196	<0.0001
Publications USA	16	176	6.8%*	19.8%	4.559	<0.0001
All Publications	64	356	14.0%*	30.8%	8.584	<0.0001
All Registrant Funded Studies	250	418	20.3%*	48.8%	8.480	<0.0001
All Canada	23	77	13.2%*	27.5%	4.196	<0.0001
All USA	291	697	15.1%*	42.9%	9.274	<0.0001
Grand Total	**314**	**774**	**17.4%***	**41.6%**	**11.619**	**<0.0001**

*Significant at 5% level.

Corn Table 2. Sample statistics for the corn yield benefit by data source for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

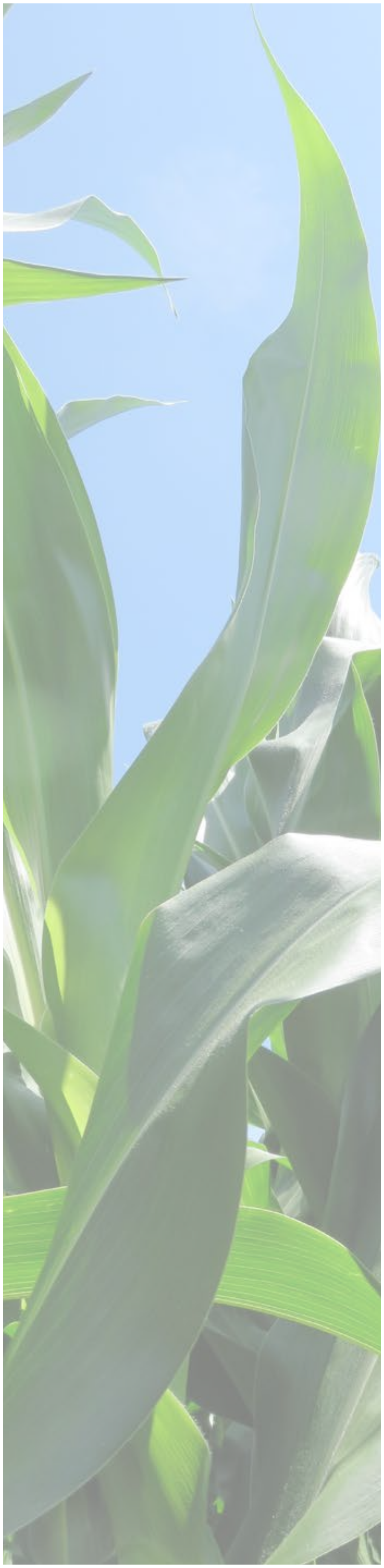
Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT	--	--	--	--	--	--
Publications Canada	12	30	9.8%	40.7%	1.321	0.0984
Publications USA	13	74	0.0%	12.0%	0.007	0.4972
All Publications	25	104	2.8%	24.2%	1.194	0.1177
All Registrant Funded Studies	181	325	4.9%*	19.9%	4.428	<0.0001
All Canada	12	30	9.8%	40.7%	1.321	0.0984
All USA	194	399	4.0%*	18.8%	4.239	<0.0001
Grand Total	**206**	**429**	**4.4%***	**21.0%**	**4.327**	**<0.0001**

*Significant at 5% level.

Corn Table 3. Sample statistics for the corn yield benefit by state/province for neonicotinoid treatments relative to untreated control treatments.

State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AR	35	5.4%*	12.9%	2.485	0.0090
BC	1	34.2%	--	--	--
DE	24	49.5%*	66.0%	3.669	0.0006
GA	13	87.8%*	77.9%	4.066	0.0008
IA	64	6.8%*	26.2%	2.079	0.0209
IL	79	20.1%*	38.7%	4.630	<0.0001
IN	21	3.5%	29.3%	0.554	0.2930
KS	144	5.4%*	18.5%	3.493	0.0003
KY	6	7.9%*	7.6%	2.559	0.0253
LA	27	18.6%*	12.6%	7.651	<0.0001
MD	2	1.9%	2.7%	1.000	0.2500
MI	6	9.3%	15.7%	1.451	0.1033
MN	6	-13.3%	30.0%	-1.086	0.1636
MO	11	7.1%*	8.2%	2.862	0.0084
MS	1	-1.1%	--	--	--
NC	18	104.6%*	116.6%	3.804	0.0007
ND	1	3.3%	--	--	--
NE	70	14.2%*	18.6%	6.356	<0.0001
NY	6	3.3%	5.0%	1.591	0.0863
OH	48	5.3%*	13.1%	2.812	0.0036
ON	76	12.9%*	27.6%	4.070	0.0001
PA	12	47.6%*	87.0%	1.896	0.0423
SD	7	11.3%*	8.1%	3.674	0.0052
TN	1	7.2%	--	--	--
TX	58	38.2%*	58.5%	4.982	<0.0001
VA	8	7.6%*	7.4%	2.886	0.0117
WI	29	11.9%*	7.5%	8.569	<0.0001
ALL	**774**	**17.4%***	**41.6%**	**11.619**	**<0.0001**

*Significant at 5% level.

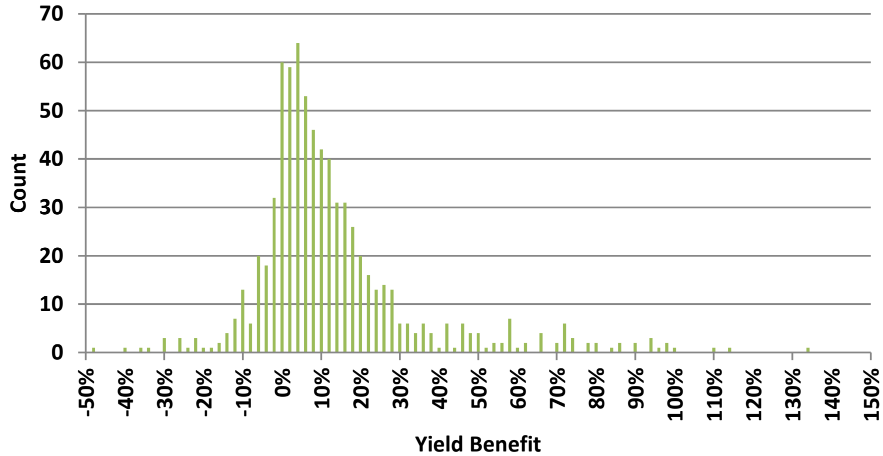


Corn Table 4. Sample statistics for the corn yield benefit by state/province for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

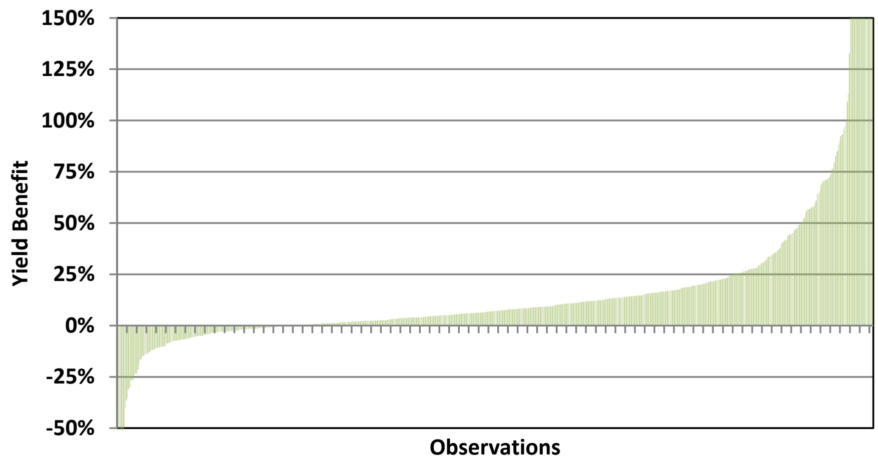
State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AR	27	5.6%*	12.8%	2.258	0.0163
BC	1	43.2%	--	--	--
DE	6	17.8%*	19.7%	2.208	0.0391
IA	44	8.0%	32.2%	1.656	0.0525
IL	76	-3.7%*	10.6%	-3.043	0.0016
IN	18	-0.3%	10.2%	-0.138	0.4459
KS	41	0.7%	11.2%	0.427	0.3358
KY	6	2.7%	4.9%	1.358	0.1163
LA	4	5.4%*	3.2%	3.425	0.0208
MN	5	16.8%*	10.0%	3.746	0.0100
MO	11	2.7%*	3.9%	2.310	0.0217
NC	14	41.6%*	42.4%	3.671	0.0014
ND	1	13.2%	--	--	--
NE	38	2.2%	12.5%	1.068	0.1462
NY	4	2.5%	4.0%	1.227	0.1537
OH	24	1.8%*	4.8%	1.870	0.0371
ON	29	8.7%	40.9%	1.140	0.1319
PA	10	-6.7%*	8.9%	-2.378	0.0207
SD	7	19.8%*	17.5%	2.984	0.0123
TX	36	8.0%*	16.1%	2.977	0.0026
VA	2	1.4%	5.6%	0.356	0.3913
WI	25	-0.4%	4.5%	-0.401	0.3459
ALL	**429**	**4.4%***	**21.0%**	**4.327**	**<0.0001**

*Significant at 5% level.

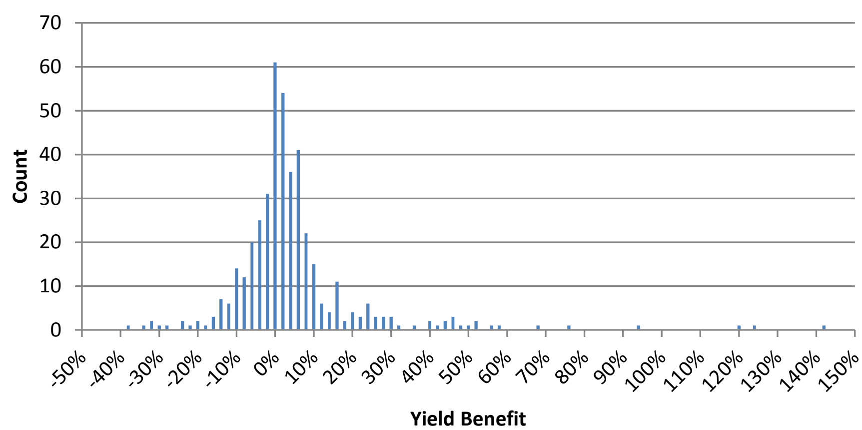
Corn Figure 1. Histogram of corn yield benefits for neonicotinoid treatments relative to untreated control treatment, truncated at –50% and +150% (N = 774, minimum = –89.73%, maximum = 329.98%, average = 17.38%, standard deviation = 41.60%, t = 11.619, p = <0.0001).



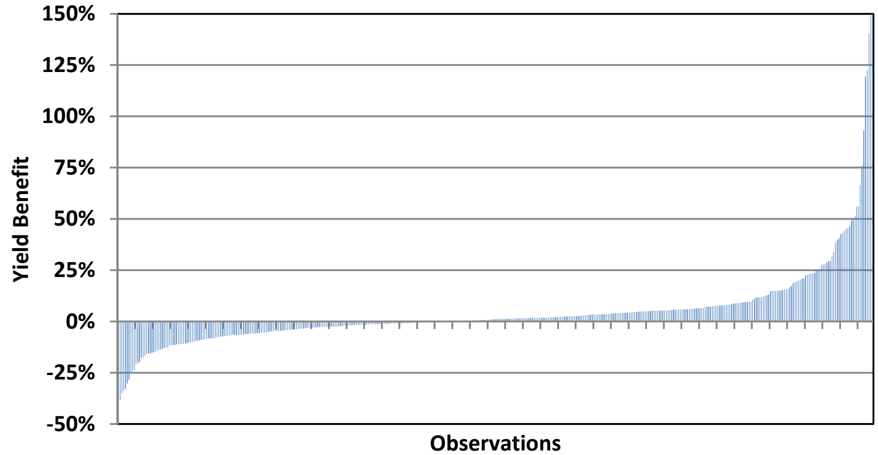
Corn Figure 2. Sorted bar graph of observed corn yield benefits for neonicotinoid treatments relative to untreated control treatments, truncated at –50% and +150% (N = 774, minimum = –89.73%, maximum = 329.98%, average = 17.38%, standard deviation = 41.60%, t = 11.619, p = <0.0001).



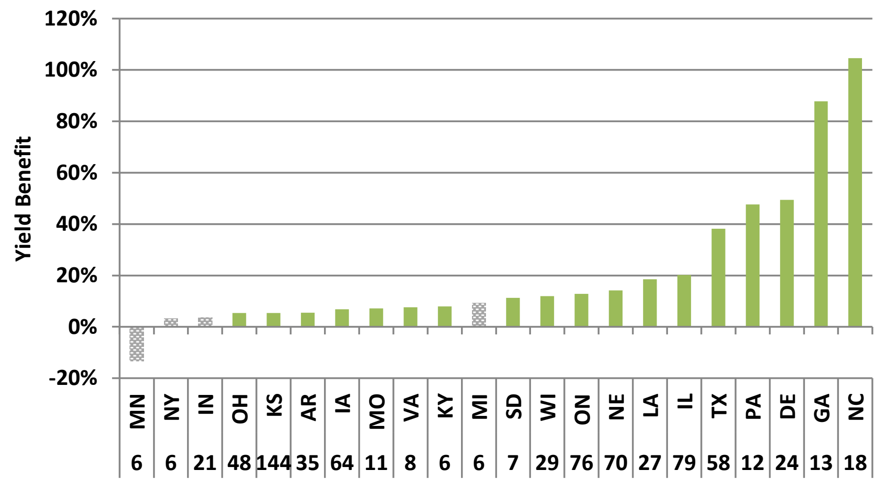
Corn Figure 3. Histogram of corn yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments, truncated at –50% and +150% (N = 429, minimum = –55.75%, maximum = 171.43%, average = 4.40%, standard deviation = 21.04%, t = 4.327, p = <0.0001).



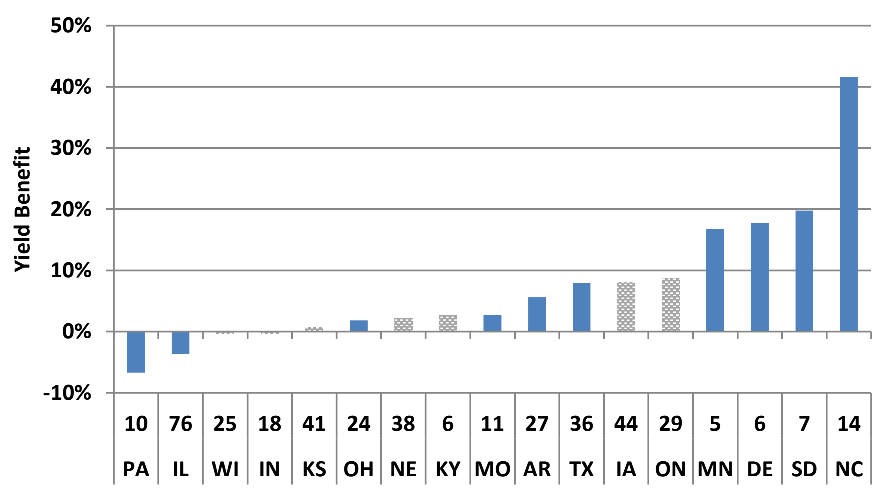
Corn Figure 4. Sorted bar graph of observed corn yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments, truncated at −50% and +150% (N = 429, minimum = −55.75%, maximum = 171.43%, average = 4.40%, standard deviation = 21.04%, t = 4.327, p = <0.0001).



Corn Figure 5. Average corn yield benefit for neonicotinoid treatments relative to untreated control treatments by state/province (only states/provinces with at least 5 observations; number of observations below each state/province abbreviation; insignificant (p > 0.05) averages in hatched gray).



Corn Figure 6. Average corn yield benefit for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments by state/province (only states/provinces with at least 5 observations; number of observations below each state/province abbreviation; insignificant (p > 0.05) averages in hatched gray).



Soybean Table 1. Sample statistics for the soybean yield benefit by data source for neonicotinoid treatments relative to untreated control treatments.

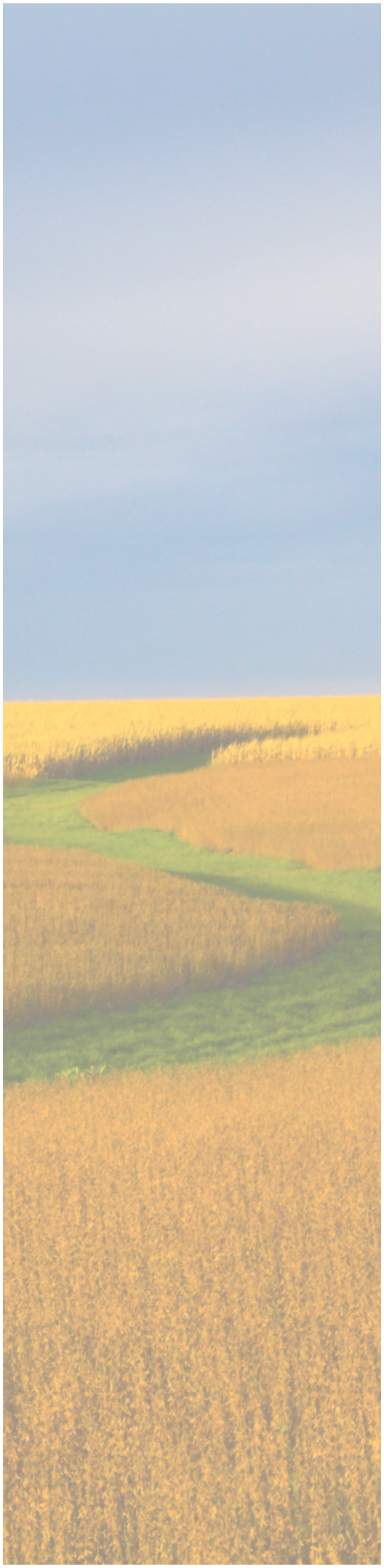
Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT	19	55	3.0%*	7.9%	2.804	0.0035
Publications Canada	9	76	10.2%*	23.7%	3.742	0.0002
Publications USA	19	94	3.3%*	6.8%	4.735	<0.0001
All Publications	47	225	5.5%*	15.3%	5.449	<0.0001
All Registrant Funded Studies	251	493	2.7%*	10.7%	5.678	<0.0001
All Canada	9	76	10.2%*	23.7%	3.742	0.0002
All USA	289	642	2.8%*	10.0%	7.201	<0.0001
Grand Total	**298**	**718**	**3.6%***	**12.4%**	**7.833**	**<0.0001**

*Significant at 5% level.

Soybean Table 2. Sample statistics for the soybean yield benefit by data source for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT	--	--	--	--	--	--
Publications Canada	--	--	--	--	--	--
Publications USA	4	11	3.3%	6.5%	1.68	0.0621
All Publications	4	11	3.3%	6.5%	1.678	0.0621
All Registrant Funded Studies	117	205	0.0%	9.0%	0.047	0.4812
All Canada	--	--	--	--	--	--
All USA	121	216	0.2%	8.9%	0.32	0.3735
Grand Total	**121**	**216**	**0.2%**	**8.9%**	**0.32**	**0.3735**

*Significant at 5% level.



Soybean Table 3. Sample statistics for the soybean yield benefit by state/province for neonicotinoid treatments relative to untreated control treatments.

State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AR	66	2.9%*	7.4%	3.130	0.0013
DE	4	4.0%	8.1%	0.988	0.1980
GA	7	3.4%	5.2%	1.736	0.0666
IA	48	2.3%*	5.3%	3.010	0.0021
IL	52	3.7%*	8.5%	3.139	0.0014
IN	15	-0.9%	8.2%	-0.416	0.3417
KS	4	2.5%	2.9%	1.768	0.0876
LA	41	0.7%	10.2%	0.424	0.3370
MI	19	3.0%*	6.6%	2.007	0.0300
MN	48	5.1%*	7.5%	4.699	<0.0001
MO	12	4.6%*	6.2%	2.566	0.0131
MS	27	5.0%*	7.8%	3.330	0.0013
NC	5	2.5%	3.4%	1.651	0.0870
NE	34	2.2%	15.5%	0.841	0.2032
NY	3	3.2%*	0.8%	6.952	0.0100
OH	55	3.0%	22.9%	0.977	0.1664
ON	76	10.2%*	23.7%	3.742	0.0002
PA	2	-5.2%	1.8%	-4.044	0.0772
SC	5	-1.2%	4.0%	-0.651	0.2752
SD	23	5.1%*	6.6%	3.718	0.0006
TN	56	2.0%*	7.5%	1.941	0.0287
TX	2	-0.9%	5.1%	-0.238	0.4256
VA	17	-0.2%	5.0%	-0.203	0.4210
WI	97	3.2%*	5.2%	6.074	<0.0001
ALL	**718**	**3.6*%**	**12.4%**	**7.833**	**<0.0001**

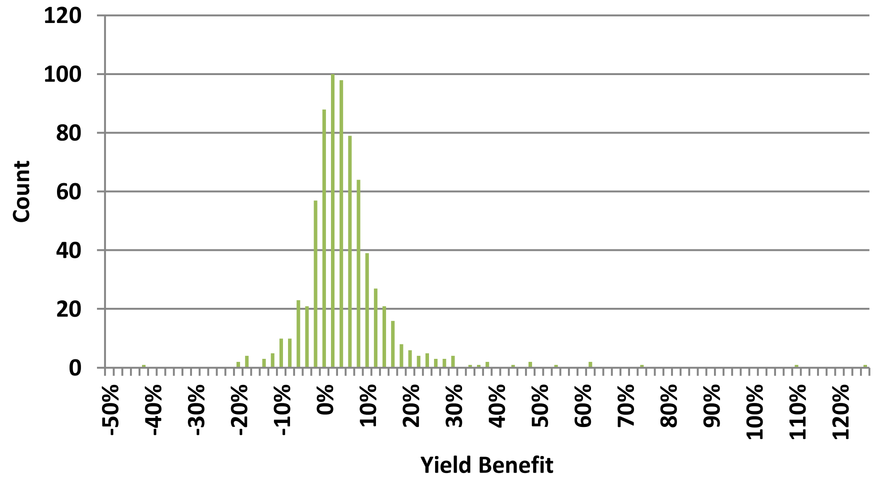
*Significant at 5% level.

Soybean Table 4. Sample statistics for the soybean yield benefit by state for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

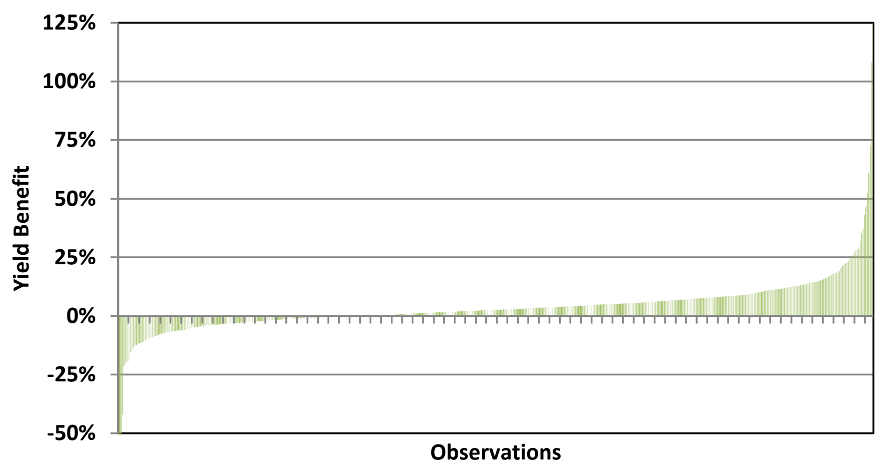
State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AR	19	2.2%	8.3%	1.163	0.1301
GA	2	0.5%	0.9%	0.690	0.3077
IA	28	-1.6%	5.7%	-1.529	0.0689
IL	24	1.3%	6.1%	1.030	0.1569
IN	4	-6.7%	10.9%	-1.237	0.1520
KS	2	4.5%*	1.0%	6.568	0.0481
LA	9	12.6%*	16.1%	2.346	0.0235
MI	8	-8.3%	15.1%	-1.565	0.0808
MN	26	-6.2%*	8.3%	-3.812	0.0004
MO	2	-1.3%	4.4%	-0.427	0.3715
MS	6	-1.6%	6.2%	-0.638	0.2759
NC	2	6.3%	6.3%	1.412	0.1962
NE	12	3.4%	8.0%	1.454	0.0869
OH	8	1.8%	4.9%	1.036	0.1673
PA	2	-1.2%	1.9%	-0.883	0.2698
SD	19	-1.7%*	3.1%	-2.345	0.0153
TN	17	7.4%*	10.3%	2.995	0.0043
TX	2	0.4%	4.9%	0.113	0.4641
WI	24	-0.1%	4.8%	-0.090	0.4646
ALL	**216**	**0.2%**	**8.9%**	**0.323**	**0.3735**

*Significant at 5% level.

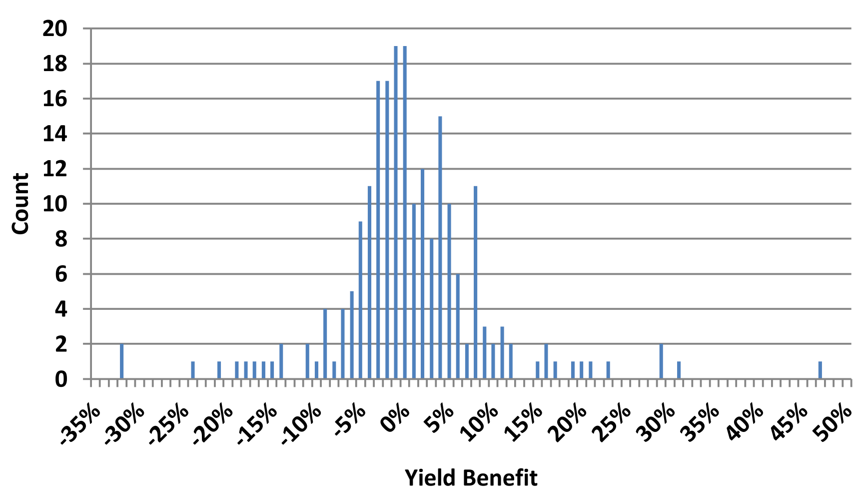
Soybean Figure 1. Histogram of soybean yield benefits for neonicotinoid treatments relative to untreated control treatment, truncated at –50% and +125% (N = 718, minimum = –77.50%, maximum = 125.00%, average = 3.62%, standard deviation = 12.38%, t = 7.833, p = <0.0001).



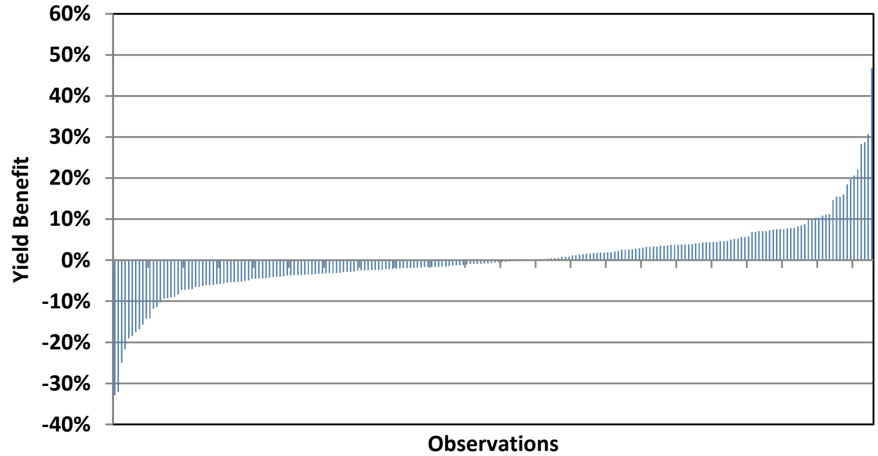
Soybean Figure 2. Sorted bar graph of observed soybean yield benefits for neonicotinoid treatments relative to untreated control treatments, truncated at –50% and +125% (N = 718, minimum = –77.50%, maximum = 125.00%, average = 3.62%, standard deviation = 12.38%, t = 7.833, p = <0.0001).



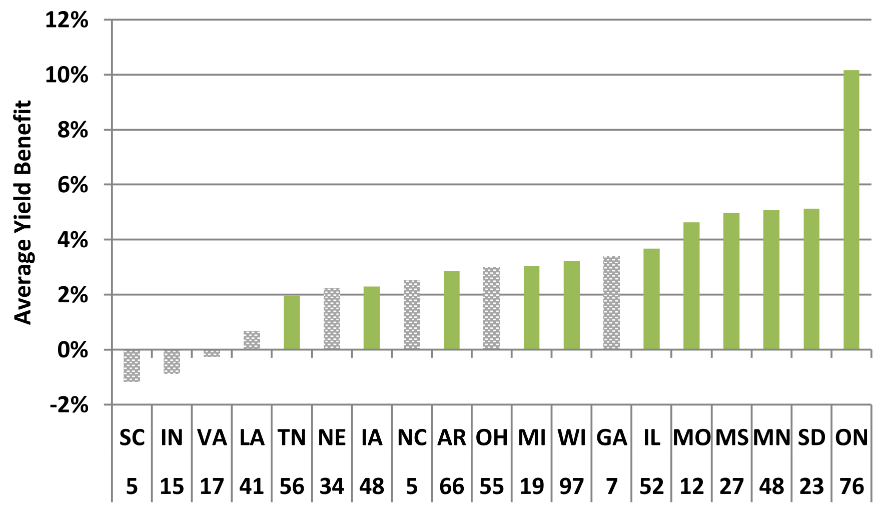
Soybean Figure 3. Histogram of soybean yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments (N = 216, minimum = –32.87%, maximum = 46.83%, average = 0.19%, standard deviation = 8.86%, t = 0.3231, p = 0.3735).



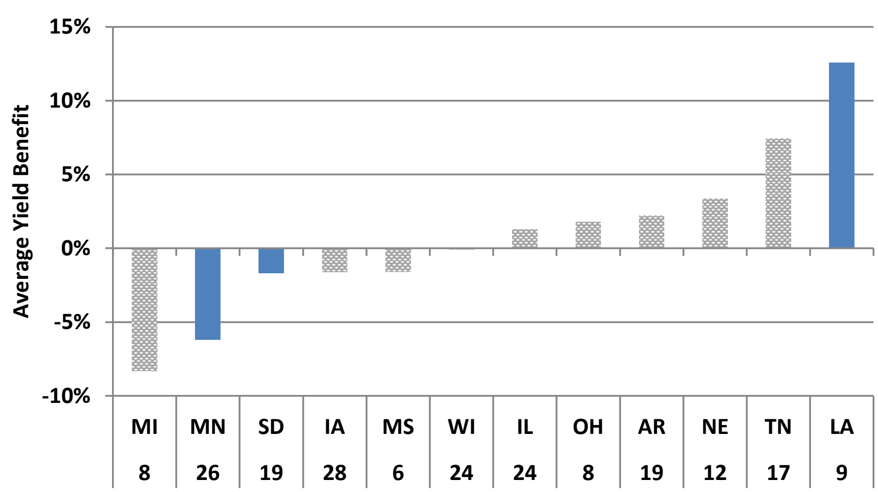
Soybean Figure 4. Sorted bar graph of observed soybean yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments (N = 216, minimum = –32.87%, maximum = 46.83%, average = 0.19%, standard deviation = 8.86%, t = 0.3231, p = 0.3735).



Soybean Figure 5. Average soybean yield benefit for neonicotinoid treatments relative to untreated control treatments by state/province (only states/provinces with at least 5 observations; number of observations below each state/province abbreviation; insignificant (p > 0.05) averages in hatched gray).



Soybean Figure 6. Average soybean yield benefit for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments by state (only states with at least 5 observations; number of observations below each state abbreviation; insignificant (p > 0.05) averages in hatched gray).



Wheat Table 1. Sample statistics for the wheat yield benefit by data source for neonicotinoid treatments relative to untreated control treatments.

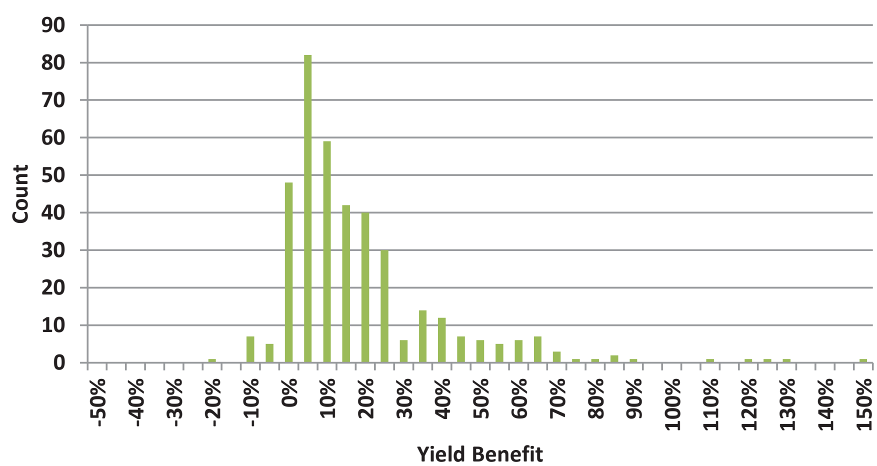
Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT	11	75	14.7%*	30.0%	4.259	<0.0001
Publications Canada	4	15	41.7%*	42.1%	3.829	0.0009
Publications USA	7	46	12.9%*	18.9%	4.628	<0.0001
All Publications	22	136	17.1%*	29.5%	6.750	<0.0001
All Registrant Funded Studies	123	260	16.6%*	27.7%	9.654	<0.0001
All Canada	4	15	41.7%*	42.1%	3.829	0.0009
All USA	141	381	15.8%*	27.3%	11.307	<0.0001
Grand Total	**145**	**396**	**16.8%***	**28.3%**	**11.782**	**<0.0001**

*Significant at 5% level.

Wheat Table 2. Sample statistics for the wheat yield benefit by data source for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT	--	--	--	--	--	--
Publications Canada	2	10	4.3%*	6.9%	1.947	0.0417
Publications USA	2	4	3.6%	6.5%	1.104	0.1752
All Publications	4	14	4.1%*	6.6%	2.321	0.0186
All Registrant Funded Studies	59	108	2.2%*	11.8%	1.942	0.0274
All Canada	2	10	4.3%*	6.9%	1.947	0.0417
All USA	61	112	2.3%*	11.6%	2.050	0.0214
Grand Total	**63**	**122**	**2.4%***	**11.3%**	**2.361**	**0.0099**

*Significant at 5% level.

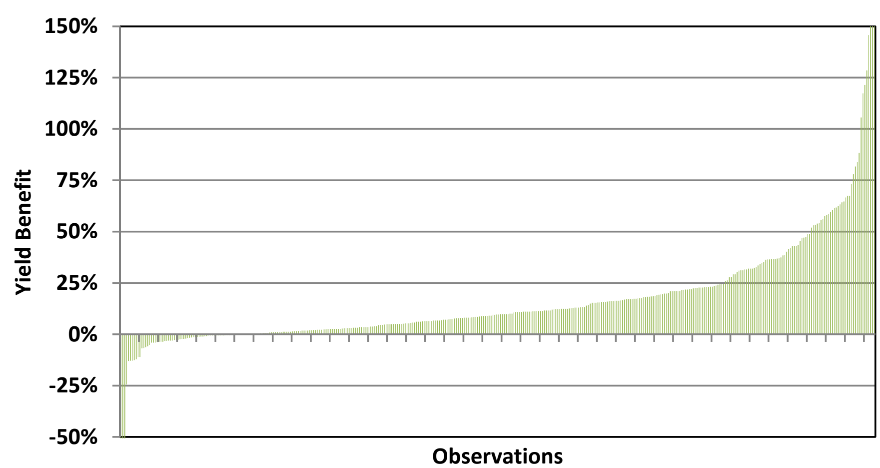


Wheat Figure 1. Histogram of wheat yield benefits for neonicotinoid treatments relative to untreated control treatment, truncated at –50% and +150% (N = 396, minimum = –63.08%, maximum = 241.76%, average = 16.77%, standard deviation = 28.32%, t = 11.782, p = <0.0001).

Wheat Table 3. Sample statistics for the wheat yield benefit by state/province for neonicotinoid treatments relative to untreated control treatments.

State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AR	2	4.6%	2.9%	2.286	0.1313
DE	9	5.6%*	6.0%	2.800	0.0116
GA	5	19.7%*	18.7%	2.348	0.0394
IA	10	17.4%*	20.8%	2.645	0.0133
IL	4	3.7%	4.4%	1.672	0.0966
IN	9	9.2%*	4.6%	5.977	0.0002
KS	1	21.0%	--	--	--
LA	22	16.6%*	17.7%	4.409	0.0001
MI	20	4.7%*	11.3%	1.838	0.0408
MN	7	7.5%	11.0%	1.793	0.0616
MO	12	22.4%	51.3%	1.509	0.0797
MS	9	-18.6%	31.0%	-1.799	0.0549
NC	38	23.4%*	24.3%	5.929	<0.0001
NE	8	1.6%	3.2%	1.410	0.1008
NY	8	8.6%*	11.7%	2.081	0.0380
OH	24	4.9%*	9.0%	2.671	0.0068
ON	15	41.7%*	42.1%	3.829	0.0009
PA	4	63.2%*	47.2%	2.679	0.0375
SC	14	2.5%*	3.4%	2.718	0.0088
SD	17	10.2%*	12.8%	3.276	0.0024
TN	27	4.5%*	12.5%	1.849	0.0379
TX	19	16.6%*	15.4%	4.714	0.0001
VA	20	10.3%*	12.4%	3.717	0.0007
WI	92	30.0%*	37.3%	7.720	<0.0001
ALL	**396**	**16.8%***	**28.3%**	**11.782**	**<0.0001**

*Significant at 5% level.

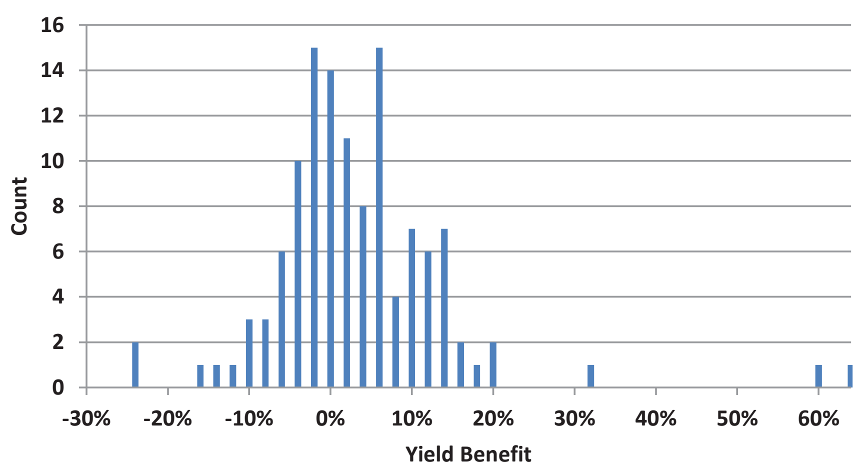


Wheat Figure 2. Sorted bar graph of observed wheat yield benefits for neonicotinoid treatments relative to untreated control treatments, truncated at –50% and +150% (N = 396, minimum = –63.08%, maximum = 241.76%, average = 16.77%, standard deviation = 28.32%, t = 11.782, p = <0.0001).

Wheat Table 4. Sample statistics for the wheat yield benefit by state/province for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

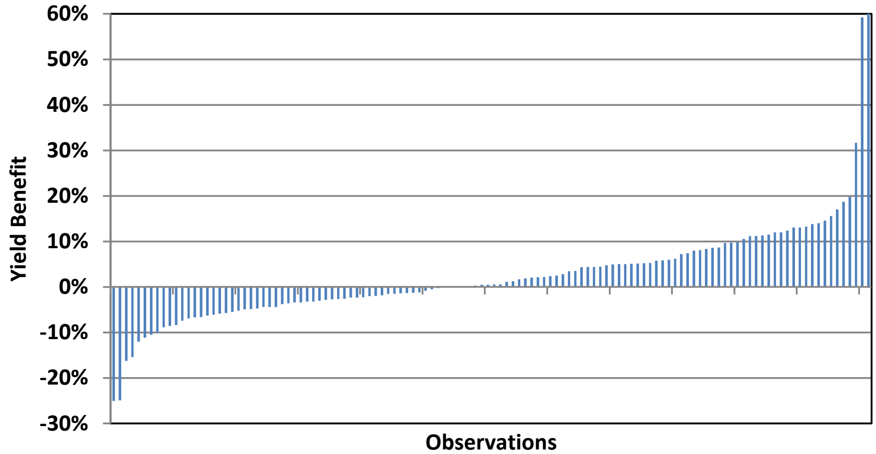
State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AR	8	3.5%	7.1%	1.392	0.1033
CA	2	1.0%	5.8%	0.249	0.4223
CO	4	8.2%	7.3%	2.243	0.0553
DE	4	-0.6%	4.1%	-0.282	0.3981
GA	7	8.9%*	7.9%	2.972	0.0125
ID	1	5.8%	--	--	--
IL	2	-3.4%	11.0%	-0.435	0.3693
KS	6	-2.8%	11.9%	-0.582	0.2928
KY	4	1.4%	3.2%	0.848	0.2293
ND	3	-0.3%	4.8%	-0.118	0.4585
ON	10	4.3%*	6.9%	1.947	0.0417
OR	3	18.0%	38.2%	0.819	0.2495
SC	10	0.4%	4.4%	0.293	0.3882
SD	1	13.8%	--	--	--
TN	15	-2.9%	7.3%	-1.519	0.0755
TX	1	5.8%	--	--	--
VA	11	2.0%	4.8%	1.380	0.0988
WA	30	2.9%	15.5%	1.014	0.1595
ALL	**122**	**2.4%***	**11.3%**	**2.361**	**0.0099**

*Significant at 5% level.

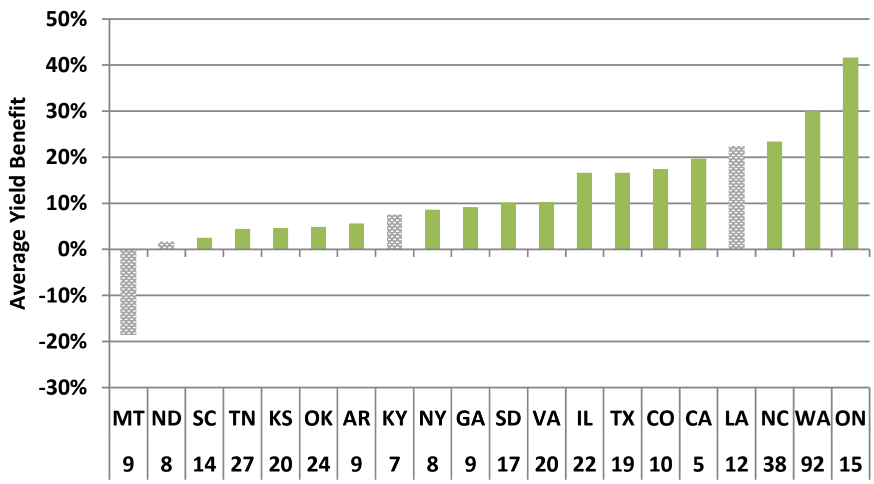


Wheat Figure 3. Histogram of wheat yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments, truncated at +60% (N = 122, minimum = –25.03%, maximum = 62.11%, average = 2.42%, standard deviation = 11.31%, t = 2.361, p = 0.0099).

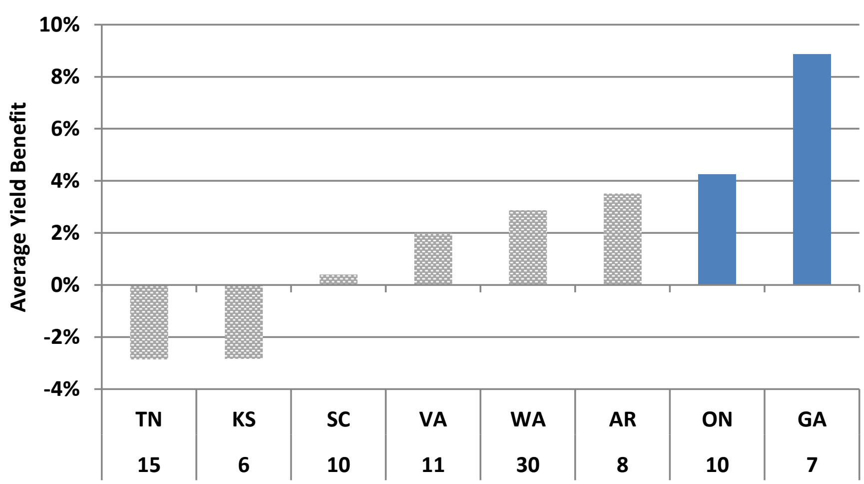
Wheat Figure 4. Sorted bar graph of observed wheat yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments, truncated at +60% (N = 122, minimum = –25.03%, maximum = 62.11%, average = 2.42%, standard deviation = 11.31%, t = 2.361, p = 0.0099).



Wheat Figure 5. Average wheat yield benefit for neonicotinoid treatments relative to untreated control treatments by state/province (only states/provinces with at least 5 observations; number of observations below each state/province abbreviation; insignificant (p > 0.05) averages in hatched gray).



Wheat Figure 6. Average wheat yield benefit for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments by state/province (only states/provinces with at least 5 observations; number of observations below each state/province abbreviation; insignificant (p > 0.05) averages in hatched gray).



Cotton Table 1. Sample statistics for the cotton yield benefit by data source for neonicotinoid treatments relative to untreated control treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT: Foliar	23	53	20.7%*	27.2%	5.533	<0.0001
AMT: Seed Treatment	45	182	21.3%*	25.1%	11.481	<0.0001
Publications: Foliar	2	6	-0.8%	1.4%	-1.424	0.1068
All Publications	70	241	20.6%*	25.4%	12.604	<0.0001
Registrant-Funded Studies						
Foliar	81	114	16.1%*	25.0%	6.867	<0.0001
Seed Treatment	99	180	13.0%*	24.1%	7.250	<0.0001
Mixed	170	211	16.4%*	29.7%	8.033	<0.0001
All Registrant-Funded Studies	350	505	15.1%*	26.8%	12.706	<0.0001
All Foliar	106	173	16.9%*	25.5%	8.718	<0.0001
All Seed Treatment	144	362	17.2%*	24.9%	13.140	<0.0001
All Mixed	170	211	16.4%*	29.7%	8.033	<0.0001
Grand Total	**420**	**746**	**16.9%***	**26.5%**	**17.465**	**<0.0001**

*Significant at 5% level.

Cotton Table 2. Sample statistics for the cotton yield benefit by data source for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT: Foliar	--	--	--	--	--	--
AMT: Seed Treatment	--	--	--	--	--	--
Publications: Foliar	2	6	-2.6%	3.2%	-1.973	0.0527
All Publications	2	6	-2.6%	3.2%	-1.973	0.0527
Registrant-Funded Studies						
Foliar	76	109	2.5%*	11.8%	2.171	0.0161
Seed Treatment	165	270	0.4%	9.2%	0.653	0.2572
Mixed	164	206	0.3%	10.1%	0.397	0.3459
All Registrant-Funded Studies	405	585	-0.7%	10.1%	1.740	0.0411
All Foliar	78	115	2.2%*	11.5%	2.031	0.0223
All Seed Treatment	165	270	0.4%	9.2%	0.653	0.2572
All Mixed	164	206	0.3%	10.1%	0.397	0.3459
Grand Total	**407**	**591**	**0.7%***	**10.0%**	**1.675**	**0.0472**

*Significant at 5% level.

Cotton Table 3. Sample statistics for the cotton yield benefit by state for neonicotinoid treatments relative to untreated control treatments.

State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AL	33	14.1%*	29.3%	2.757	0.0048
AR	170	18.5%*	28.4%	8.492	<0.0001
AZ	2	30.8%	42.8%	1.017	0.2473
CA	7	-6.4%	11.8%	-1.448	0.0988
GA	31	15.0%*	26.6%	3.139	0.0019
LA	118	15.1%*	16.8%	9.795	<0.0001
MO	11	34.5%*	43.4%	2.643	0.0123
MS	49	12.4%*	25.1%	3.466	0.0006
NC	49	21.5%*	37.6%	4.001	0.0001
OK	12	17.1%*	29.3%	2.022	0.0341
SC	11	20.9%*	17.7%	3.935	0.0014
TN	44	13.6%*	17.8%	5.069	<0.0001
TX	145	8.1%*	14.8%	6.608	<0.0001
VA	64	39.1%*	34.0%	9.206	<0.0001
ALL	**746**	**16.9%***	**26.5%**	**17.465**	**<0.0001**

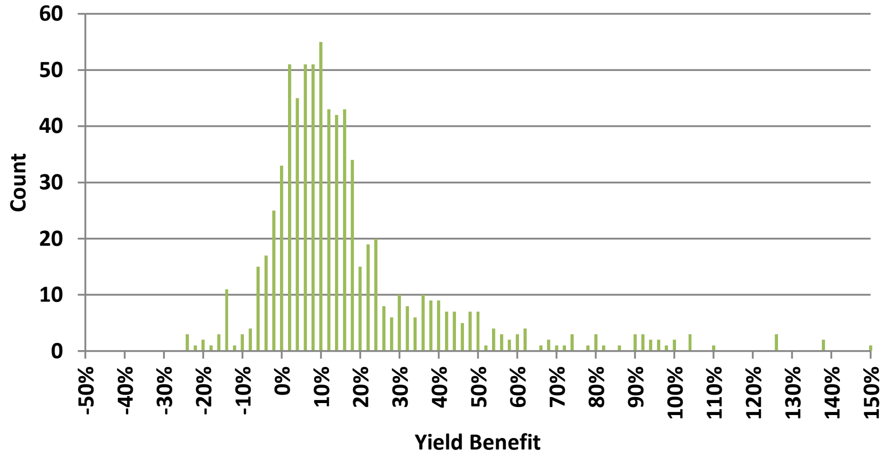
*Significant at 5% level.

Cotton Table 4. Sample statistics for the cotton yield benefit by state for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

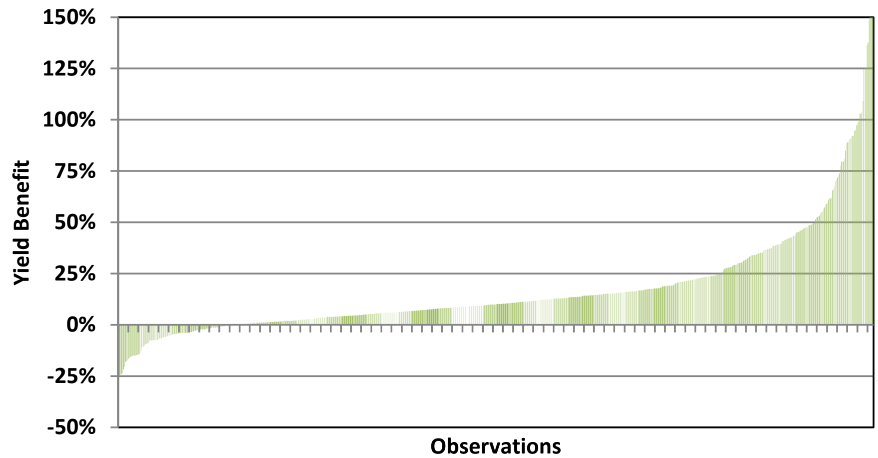
State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AL	35	0.0%	7.1%	0.022	0.4915
AR	114	3.1%*	12.5%	2.665	0.0044
AZ	4	4.0%	5.7%	1.395	0.1287
CA	8	2.0%	8.8%	0.630	0.2742
GA	32	-2.9%	12.3%	-1.328	0.0970
LA	65	-0.4%	6.8%	-0.470	0.3200
MO	7	0.0%	6.6%	0.007	0.4972
MS	51	-1.1%	9.3%	-0.823	0.2071
NC	37	0.7%	14.5%	0.292	0.3860
OK	8	4.6%	11.9%	1.089	0.1561
SC	14	-2.7%	6.1%	-1.634	0.0631
TN	59	3.3%*	7.6%	3.277	0.0009
TX	115	0.3%	8.1%	0.397	0.3460
VA	42	-1.4%	10.5%	-0.889	0.1897
ALL	**591**	**0.7%***	**10.0%**	**1.675**	**0.0472**

*Significant at 5% level.

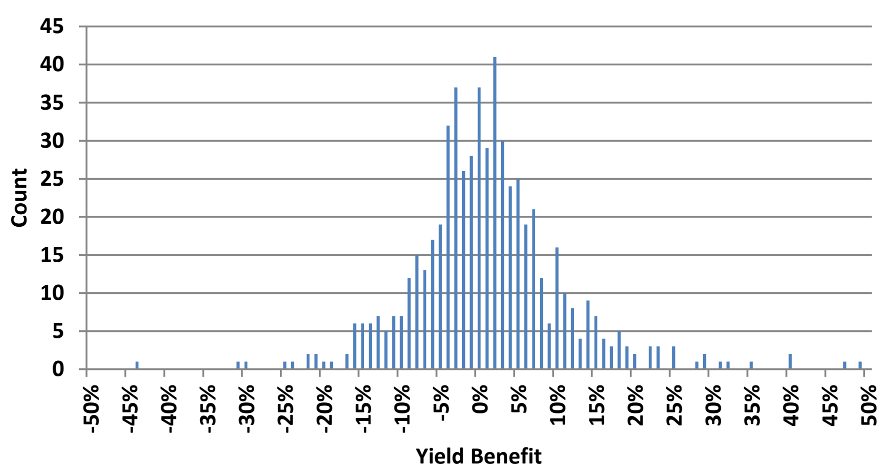
Cotton Figure 1. Histogram of cotton yield benefits for neonicotinoid treatments relative to untreated control treatment, truncated at –50% and +150% (N = 746, minimum = –55.82%, maximum = 191.77%, average = 16.92%, standard deviation = 26.46%, t = 17.47, p = <0.0001).



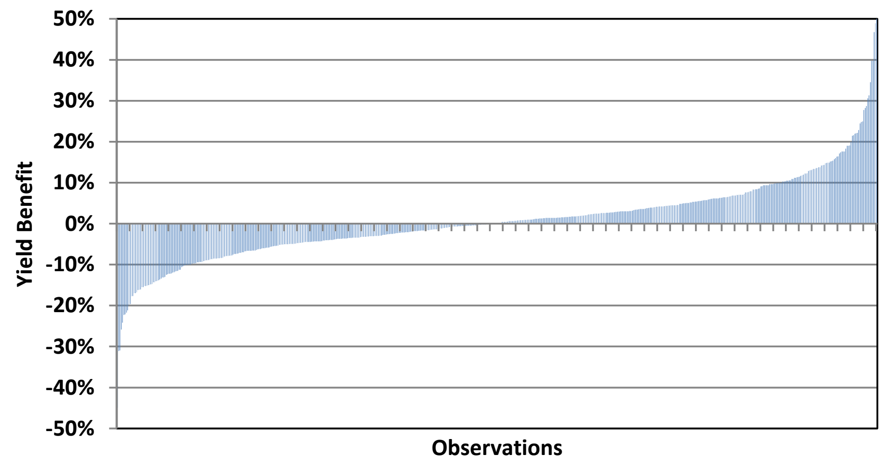
Cotton Figure 2. Sorted bar graph of observed cotton yield benefits for neonicotinoid treatments relative to untreated control treatments, truncated at –50% and +150% (N = 746, minimum = –55.82%, maximum = 191.77%, average = 16.92%, standard deviation = 26.46%, t = 17.47, p = <0.0001).



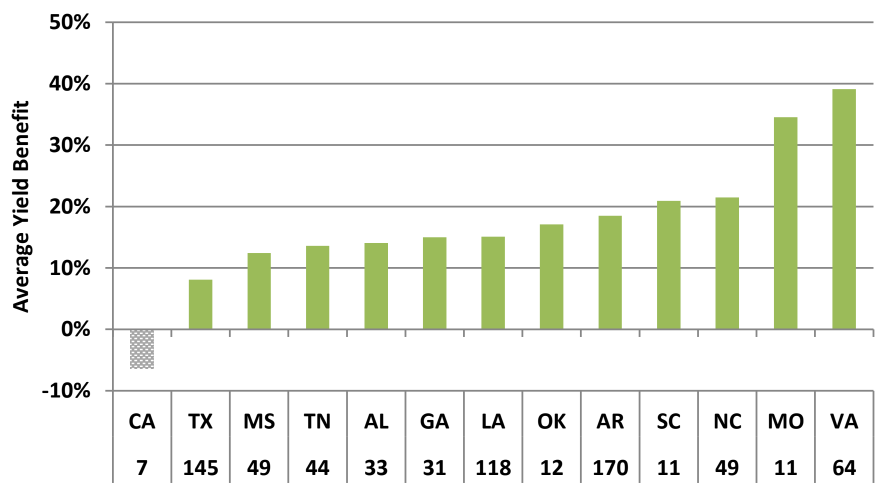
Cotton Figure 3. Histogram of cotton yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments, truncated at +50% (N = 591, minimum = –44.92%, maximum = 58.08%, average = 0.69%, standard deviation = 10.02%, t = 1.675, p = 0.0472).



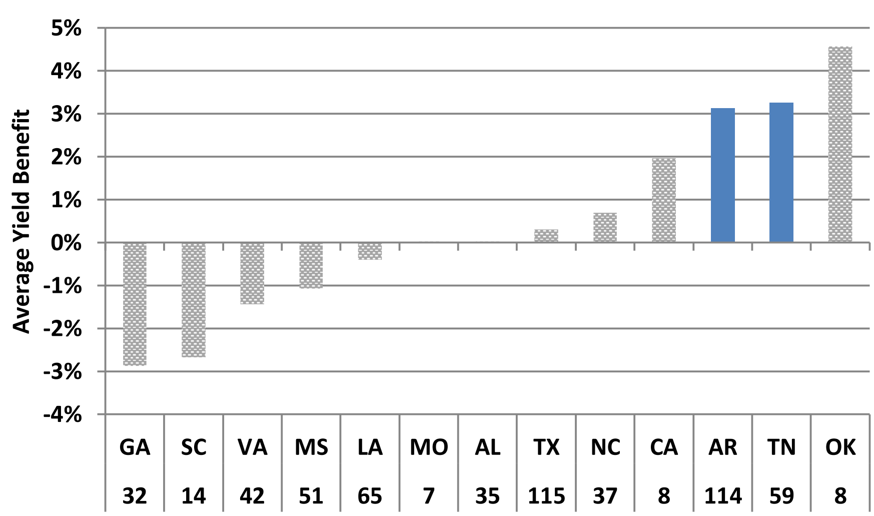
Cotton Figure 4. Sorted bar graph of observed cotton yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments, truncated at +50% (N = 591, minimum = –44.92%, maximum = 58.08%, average = 0.69%, standard deviation = 10.02%, t = 1.675, p = 0.0472).



Cotton Figure 5. Average cotton yield benefit for neonicotinoid treatments relative to untreated control treatments by state (only states with at least 5 observations; number of observations below each state abbreviation; insignificant (p > 0.05) averages in hatched gray).



Cotton Figure 6. Average cotton yield benefit for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments by state (only states with at least 5 observations; number of observations below each state abbreviation; insignificant (p > 0.05) averages in hatched gray).



Sorghum Table 1. Sample statistics for the sorghum yield benefit by data source for neonicotinoid treatments relative to untreated control treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT	1	4	0.5%	5.3%	0.174	0.4364
Other Publications	5	23	6.1%	26.3%	1.110	0.1395
All Publications	6	27	5.3%	24.3%	1.121	0.1362
Registrant-Funded Studies	67	135	23.1%*	55.7%	4.809	<0.0001
Grand Total	**73**	**162**	**20.1%***	**52.2%**	**4.901**	**<0.0001**

*Significant at 5% level.

Sorghum Table 2. Sample statistics for the sorghum yield benefit by data source for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications	--	--	--	--	--	--
AMT	--	--	--	--	--	--
Other Publications	--	--	--	--	--	--
All Publications	--	--	--	--	--	--
Registrant-Funded Studies	43	77	5.9*	22	2.561	0.0062
Grand Total	**43**	**77**	**5.9***	**22**	**2.561**	**0.0062**

*Significant at 5% level.

Sorghum Table 3. Sample statistics for the sorghum yield benefit by state/province for neonicotinoid treatments relative to untreated control treatments.

State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AR	4	46.5%*	31.7%	2.936	0.0303
CO	2	3.8%	1.0%	5.453	0.0577
KS	60	1.8%*	2.6%	5.415	<0.0001
LA	15	-0.5%	8.7%	-0.220	0.4145
NE	1	1.9%	--	--	--
OK	6	17.4%*	20.6%	2.076	0.0463
ON	2	-40.5%	32.3%	-1.774	0.1634
TX	72	40.8%*	71.5%	4.839	<0.0001
ALL	**162**	**20.1%***	**52.2%**	**4.901**	**<0.0001**

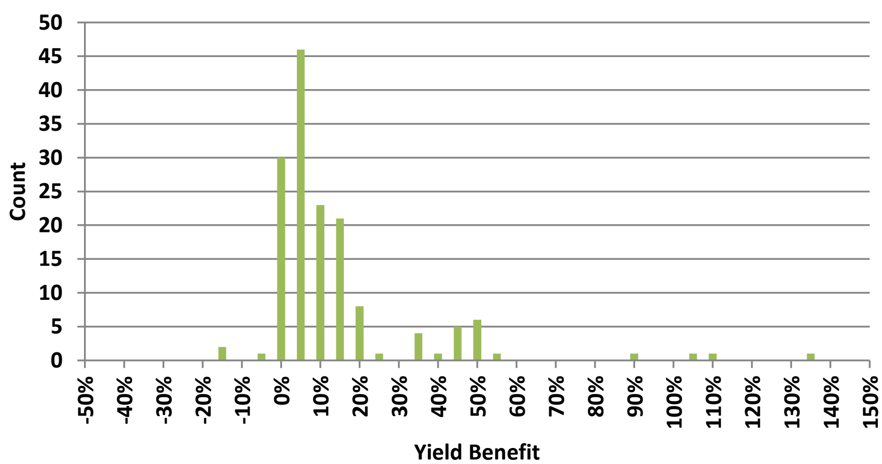
*Significant at 5% level.

Sorghum Table 4. Sample statistics for the sorghum yield benefit by state/province for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

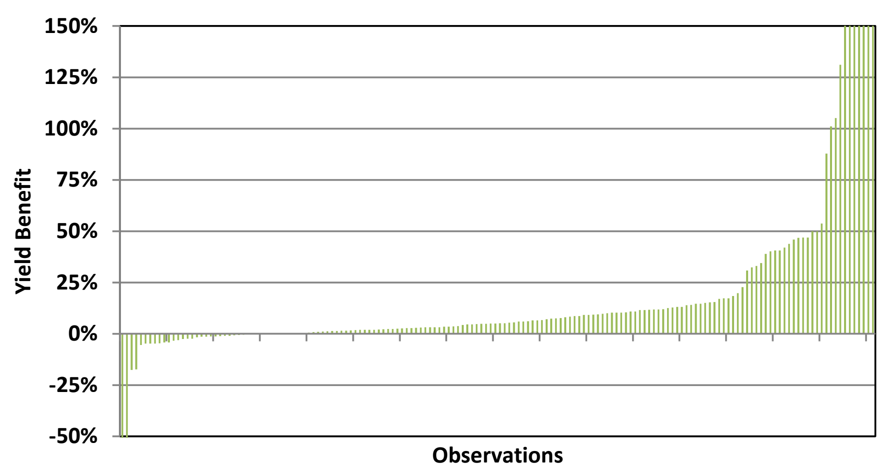
State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AR	1	13.2%	--	--	--
KS	21	5.5%	21.4%	1.180	0.1260
LA	2	4.0%*	0.3%	16.323	0.0195
NE	1	3.9%	--	--	--
OK	3	7.4%	4.7%	2.738	0.0558
TX	49	5.9%*	21.2%	1.953	0.0283
ALL	**77**	**5.9%***	**20.2%**	**2.561**	**0.0062**

*Significant at 5% level.

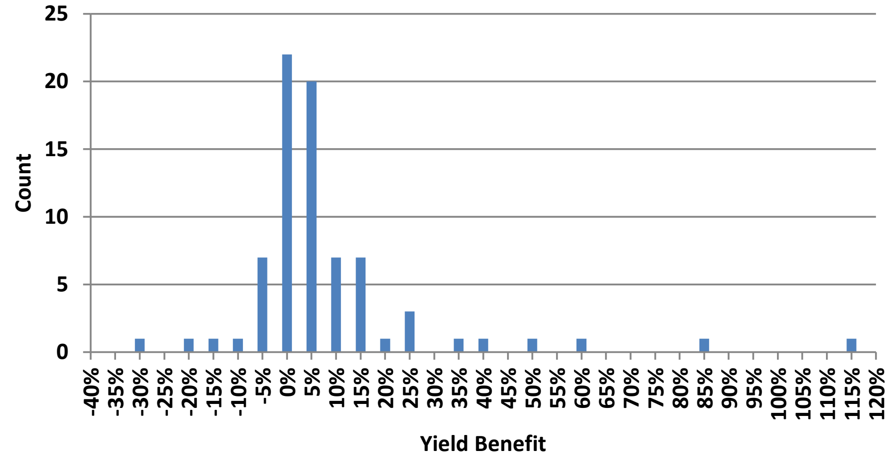
Sorghum Figure 1. Histogram of sorghum yield benefits for neonicotinoid treatments relative to untreated control treatment, truncated at –50% and +150% (N = 162, minimum = –69.46%, maximum = 309.91%, average = 20.10%, standard deviation = 52.20%, t = 4.901, p = <0.0001).



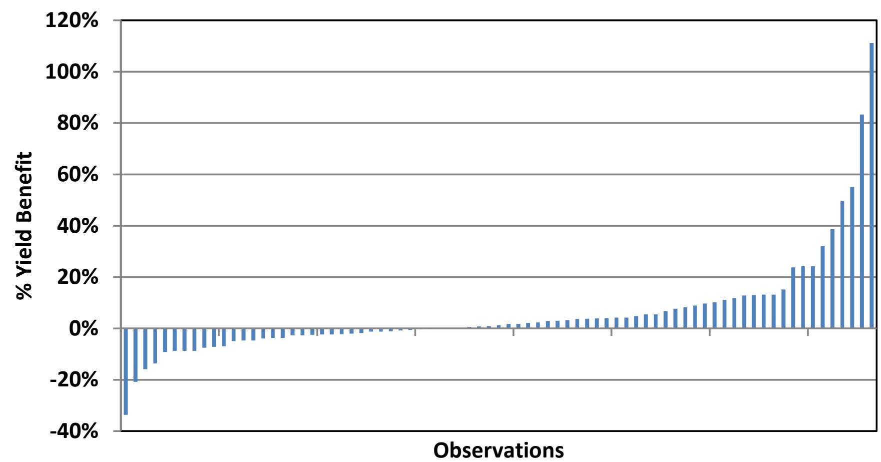
Sorghum Figure 2. Sorted bar graph of observed sorghum yield benefits for neonicotinoid treatments relative to untreated control treatments, truncated at –50% and +150% (N = 162, minimum = –69.46%, maximum = 309.91%, average = 20.10%, standard deviation = 52.20%, t = 4.901, p = <0.0001).



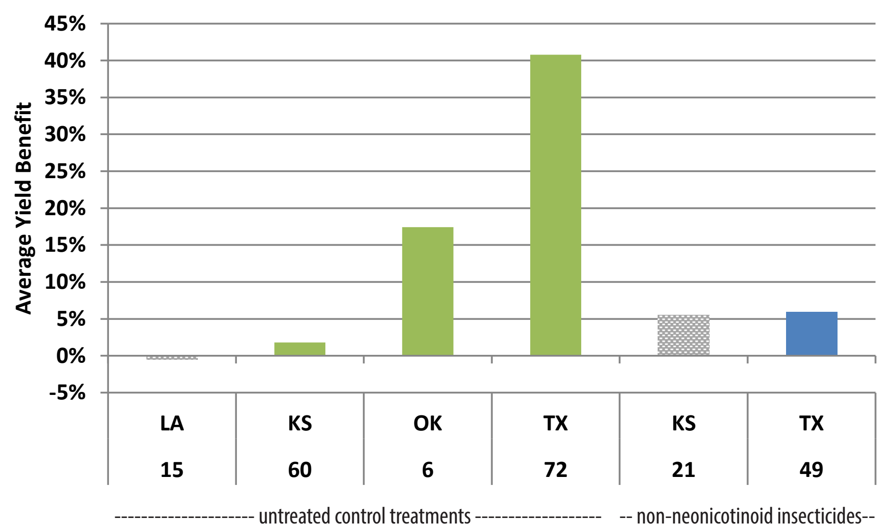
Sorghum Figure 3. Histogram of sorghum yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments (N = 77, minimum = –33.69%, maximum = 111.14%, average = 5.88%, standard deviation = 20.16%, t = 2.561, p = 0.0062).



Sorghum Figure 4. Sorted bar graph of observed sorghum yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments (N = 77, minimum = –33.69%, maximum = 111.14%, average = 5.88%, standard deviation = 20.16%, t = 2.561, p = 0.0062).



Sorghum Figure 5. Average sorghum yield benefit for neonicotinoid treatments relative to untreated control treatments (green) and relative to non-neonicotinoid insecticide treatments (blue) by state (only states with at least 5 observations; number of observations below each state abbreviation; insignificant (p > 0.05) averages in hatched gray).



Sorghum Figure 6. Figure not applicable, as data are reported in Sorghum Figure 5.

Canola Table 1. Sample statistics for the canola yield benefit by data source for neonicotinoid treatments relative to untreated control treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT	7	17	47.3%*	46.2%	4.223	0.0003
Publications Canada	1	4	32.4%	37.6%	1.721	0.0919
Publications USA	3	25	39.9%*	50.0%	3.984	0.0003
All Publications	11	46	42.0%*	47.0%	6.056	<0.0001
All Registrant Funded Studies	73	132	32.2%*	50.1%	7.391	<0.0001
All Canada	30	56	10.6%*	33.3%	2.390	0.0101
All USA	54	122	36.7%*	49.1%	8.261	<0.0001
Grand Total	**84**	**178**	**34.9%***	**48.5%**	**8.237**	**<0.0001**

*Significant at 5% level.

Canola Table 2. Sample statistics for the canola yield benefit by data source for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications						
AMT	--	--	--	--	--	--
Publications Canada	--	--	--	--	--	--
Publications USA	2	23	4.5%	52.6%	0.408	0.3436
All Publications	2	23	4.5%	52.6%	0.408	0.3436
All Registrant Funded Studies	50	88	11.1%	42.5%	2.442	0.0083
All Canada	30	54	18.9%	49.2%	2.827	0.0033
All USA	22	57	0.9%	38.0%	0.184	0.4273
Grand Total	**52**	**111**	**9.7%***	**44.6%**	**2.291**	**0.0119**

*Significant at 5% level.

Canola Table 3. Sample statistics for the canola yield benefit by state/province for neonicotinoid treatments relative to untreated control treatments.

State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
GA	4	-3.2%	13.7%	-0.465	0.3367
ID	5	30.2%*	20.5%	3.290	0.0151
MB	9	22.4%*	26.9%	2.499	0.0185
MN	12	11.0%*	16.4%	2.329	0.0200
MT	7	11.4%	32.8%	0.918	0.1969
ND	55	42.7%*	55.3%	5.729	0.0000
ON	28	25.2%*	42.9%	3.104	0.0022
OR	8	22.4%*	33.4%	1.900	0.0496
SK	19	42.3%*	66.5%	2.774	0.0063
WA	31	51.5%*	50.7%	5.656	0.0000
ALL	**178**	**34.8%***	**49.4%**	**9.389**	**0.0000**

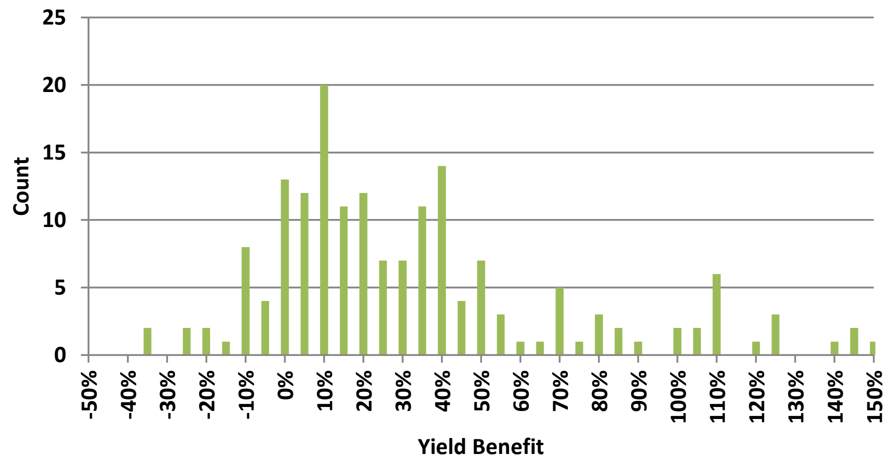
*Significant at 5% level.

Canola Table 4. Sample statistics for the canola yield benefit by state/province for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

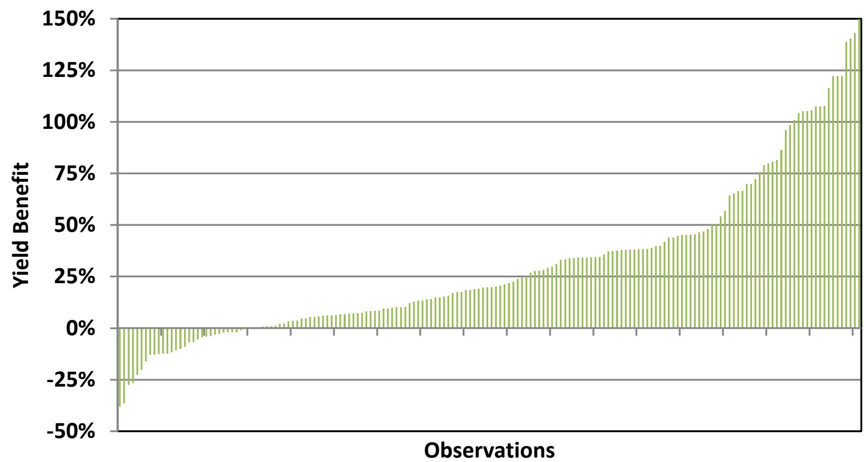
State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
AB	2	24.3%	21.4%	1.606	0.1773
GA	2	3.7%	7.0%	0.753	0.2945
ID	5	6.3%	11.9%	1.181	0.1515
MB	7	21.1%	30.4%	1.836	0.0580
MT	7	1.1%	40.8%	0.070	0.4733
ND	27	2.5%	48.5%	0.265	0.3965
ON	28	15.1%	55.6%	1.441	0.0805
OR	7	1.2%	31.6%	0.101	0.4615
SK	17	23.7%*	48.9%	1.999	0.0314
WA	9	-7.7%	16.8%	-1.367	0.1044
ALL	**111**	**9.7%***	**44.6%**	**2.291**	**0.0119**

*Significant at 5% level.

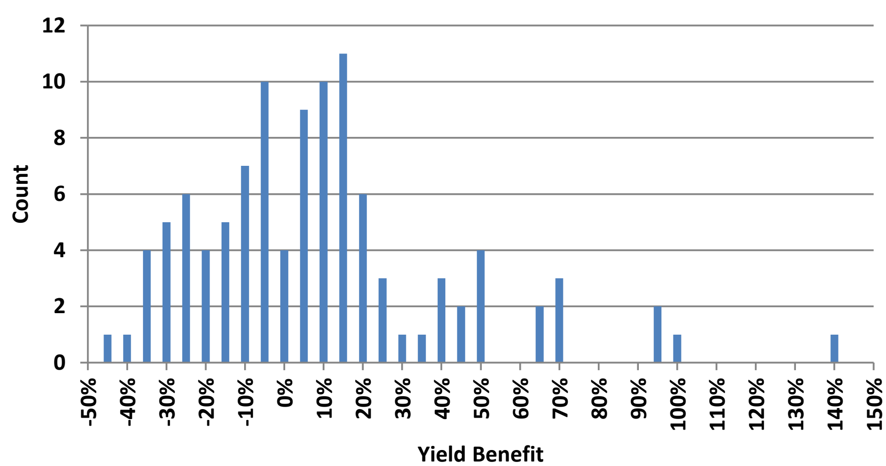
Canola Figure 1. Histogram of canola yield benefits for neonicotinoid treatments relative to untreated control treatment, truncated at –50% and +150% (N = 178, minimum = –81.63%, maximum = 267.49%, average = 34.75%, standard deviation = 49.38%, t = 9.389, p = <0.0001).



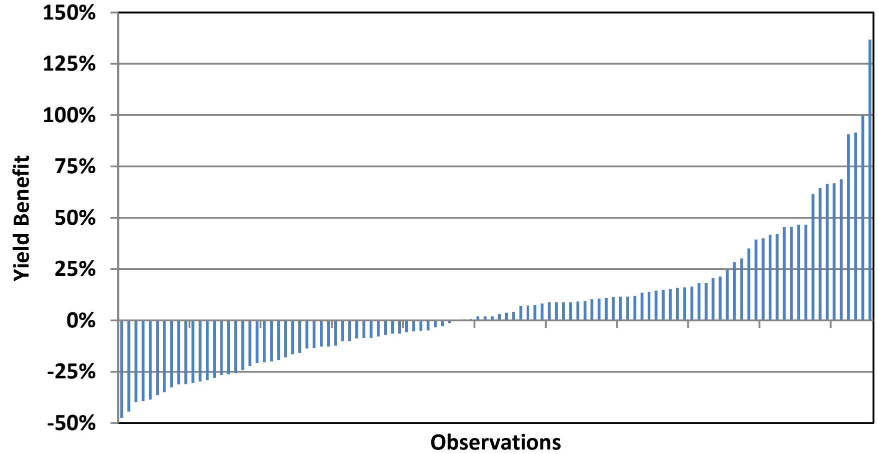
Canola Figure 2. Sorted bar graph of observed canola yield benefits for neonicotinoid treatments relative to untreated control treatments, truncated at –50% and +150% (N = 178, minimum = –81.63%, maximum = 267.49%, average = 34.75%, standard deviation = 49.38%, t = 9.389, p = <0.0001).



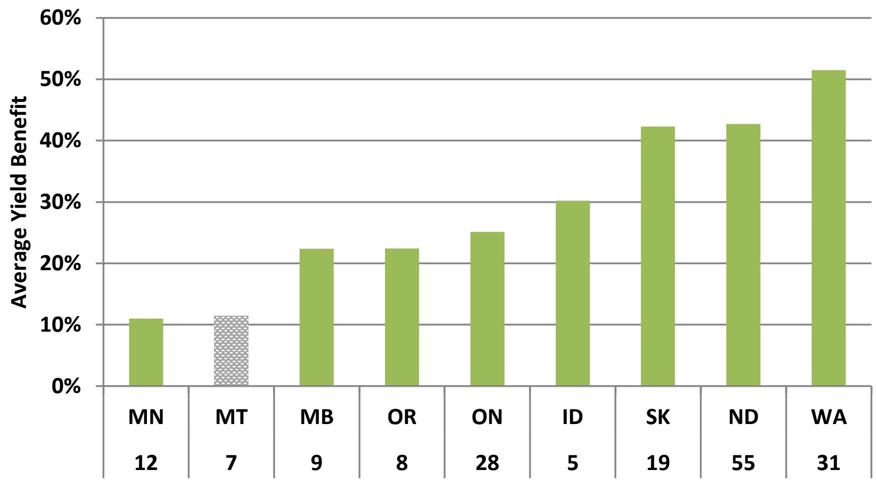
Canola Figure 3. Histogram of canola yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments, truncated at –50% and +150% (N = 111, minimum = –88.37%, maximum = 205.86%, average = 9.69%, standard deviation = 44.57%, t = 2.291, p = 0.0119).



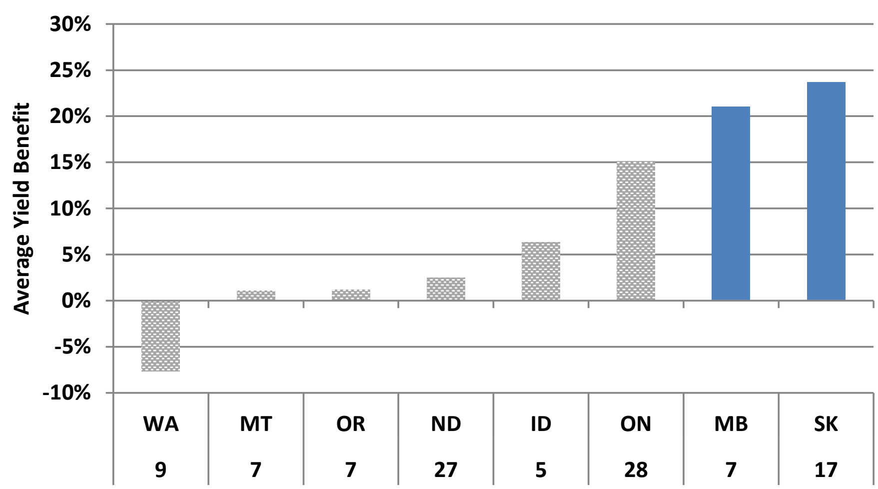
Canola Figure 4. Sorted bar graph of observed canola yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments, truncated at –50% and +150% (N = 111, minimum = –88.37%, maximum = 205.86%, average = 9.69%, standard deviation = 44.57%, t = 2.291, p = 0.0119).



Canola Figure 5. Average canola yield benefit for neonicotinoid treatments relative to untreated control treatments by state/province (only states/provinces with at least 5 observations; number of observations below each state/province abbreviation; insignificant (p > 0.05) averages in hatched gray).



Canola Figure 6. Average canola yield benefit for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments by state/province (only states/provinces with at least 5 observations; number of observations below each state/province abbreviation; insignificant (p > 0.05) averages in hatched gray).



Potato Table 1. Sample statistics for the potato yield benefit by data source for neonicotinoid treatments relative to untreated control treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications AMT	21	41	59.9%*	55.3%	6.942	<0.0001
All Registrant Funded Studies	173	265	73.1%*	116.4%	10.218	<0.0001
Grand Total	**194**	**306**	**71.3%***	**110.3%**	**11.316**	**<0.0001**

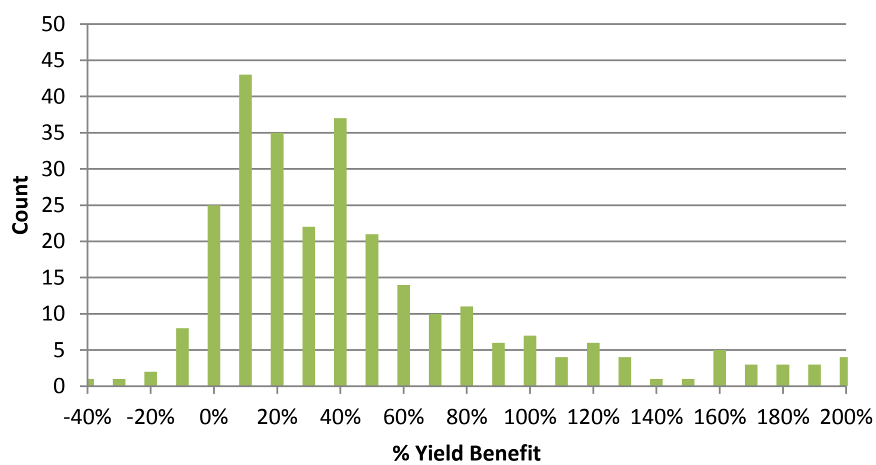
*Significant at 5% level.

Potato Table 2. Sample statistics for the potato yield benefit by data source for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

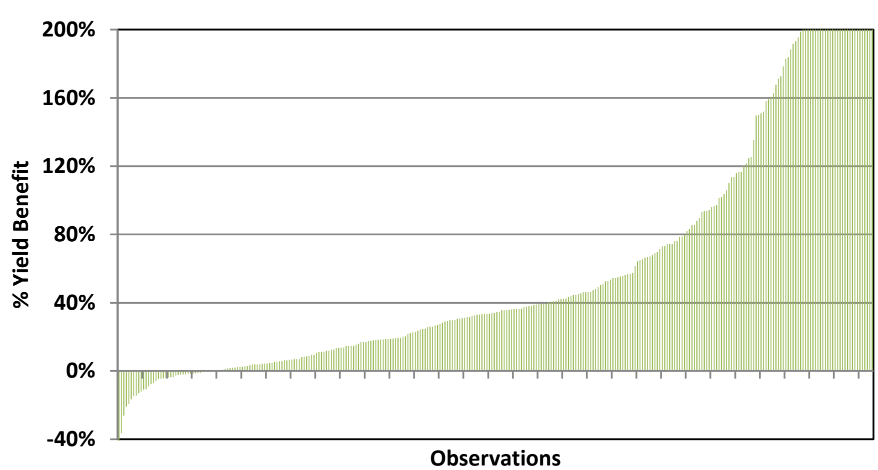
Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications AMT	--	--	--	--	--	--
All Registrant Funded Studies	63	109	12.6%*	22.7%	5.810	<0.0001
Grand Total	**63**	**109**	**12.6%***	**22.7%**	**5.810**	**<0.0001**

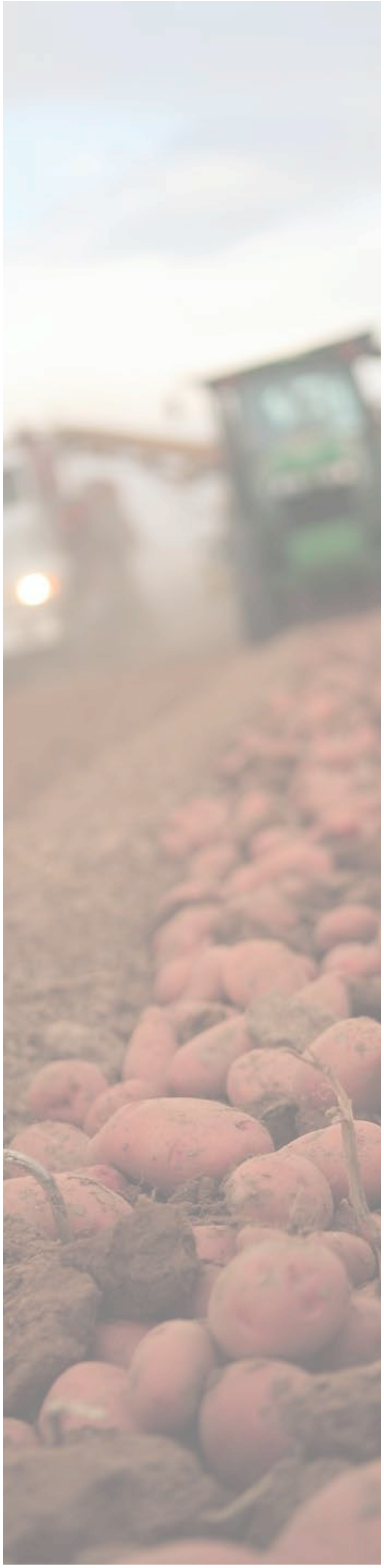
*Significant at 5% level.

Potato Figure 1. Histogram of potato yield benefits for neonicotinoid treatments relative to untreated control treatment, truncated at –40% and +200% (N = 306, minimum = –41.94%, maximum = 726.39%, average = 71.33%, standard deviation = 110.26%, t = 11.316, p = <0.0001).



Potato Figure 2. Sorted bar graph of observed potato yield benefits for neonicotinoid treatments relative to untreated control treatments, truncated at –40% and +200% (N = 306, minimum = –41.94%, maximum = 726.39%, average = 71.33%, standard deviation = 110.26%, t = 11.316, p = <0.0001).





Potato Table 3. Sample statistics for the potato yield benefit by state/province for neonicotinoid treatments relative to untreated control treatments.

State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
CO	1	5.4%	--	--	--
DE	1	8.6%	--	--	--
FL	3	-0.5%	9.0%	-0.087	0.4694
ID	28	21.2%*	23.0%	4.878	<0.0001
IN	4	58.7%*	14.5%	8.104	0.0020
MD	5	90.5%*	66.5%	3.040	0.0192
ME	19	20.2%*	28.3%	3.117	0.0030
MI	34	147.8%*	209.5%	4.115	0.0001
MN	17	77.2%*	94.6%	3.366	0.0020
MT	12	4.3%	15.5%	0.955	0.1800
NB	1	32.4%	--	--	--
NC	13	7.8%*	8.2%	3.446	0.0024
ND	6	5.2%	11.4%	1.113	0.1582
NE	3	6.0%	19.6%	0.531	0.3243
NJ	5	51.8%*	12.2%	9.512	0.0003
NY	36	153.0%*	120.7%	7.607	<0.0001
OH	12	43.5%*	15.9%	9.488	<0.0001
ON	1	64.2%	--	--	--
OR	8	21.4%*	17.9%	3.388	0.0058
PE	1	11.2%	--	--	--
TN	1	76.0%	--	--	--
TX	5	50.0%*	27.5%	4.066	0.0076
VA	33	85.4%*	83.8%	5.854	<0.0001
WA	20	6.3%*	11.3%	2.509	0.0107
WI	34	110.7%*	108.8%	5.935	<0.0001
WY	3	1.8%	6.0%	0.521	0.3273
ALL	**306**	**71.3%***	**110.3%**	**11.316**	**<0.0001**

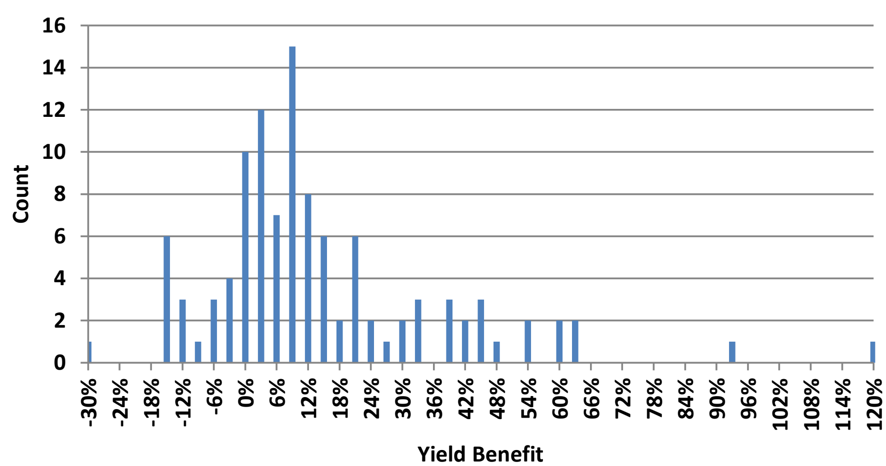
*Significant at 5% level.

Potato Table 4. Sample statistics for the potato yield benefit by state/province for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments.

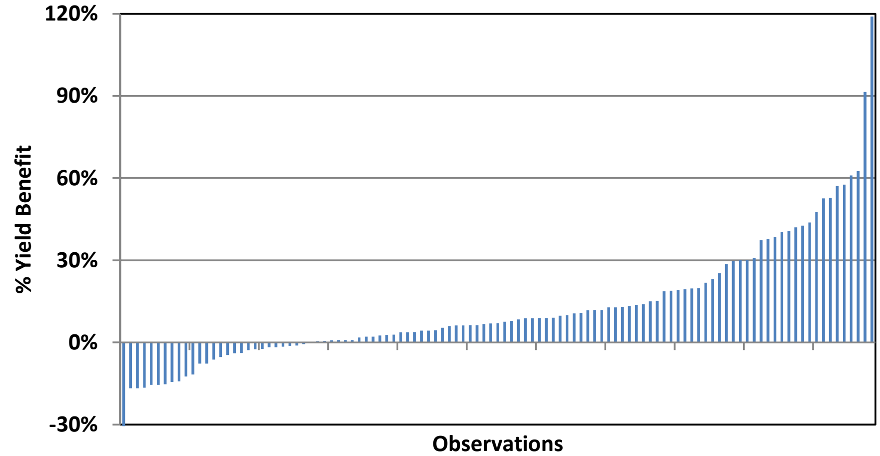
State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
DE	1	30.2%	--	--	--
FL	2	-4.5%	2.5%	-2.573	0.1180
ID	9	7.0%*	7.3%	2.867	0.0105
ME	5	12.7%*	13.2%	2.149	0.0490
MI	21	14.3%*	18.5%	3.534	0.0010
MN	3	45.2%	64.1%	1.223	0.1729
MT	1	0.0%	--	--	--
NC	12	-3.2%	10.5%	-1.052	0.1577
NY	23	23.1%*	24.6%	4.501	0.0001
OH	4	13.8%	30.9%	0.894	0.2186
OR	6	10.6%	18.4%	1.408	0.1091
TX	2	8.4%	3.1%	3.835	0.0812
VA	12	17.9%*	24.9%	2.500	0.0148
WA	3	-8.2%*	3.3%	-4.380	0.0242
WI	5	-4.7%	9.4%	-1.107	0.1652
ALL	**109**	**12.6%***	**22.7%**	**5.810**	**<0.0001**

*Significant at 5% level.

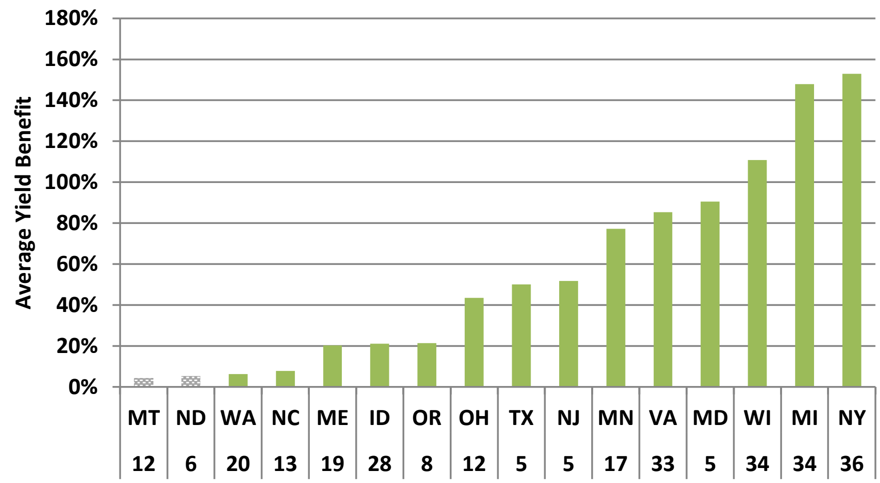
Potato Figure 3. Histogram of potato yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments, truncated at –30% (N = 109, minimum = –34.06%, maximum = 119.00%, average = 12.64%, standard deviation = 22.72%, t = 5.810, p = <0.0001).



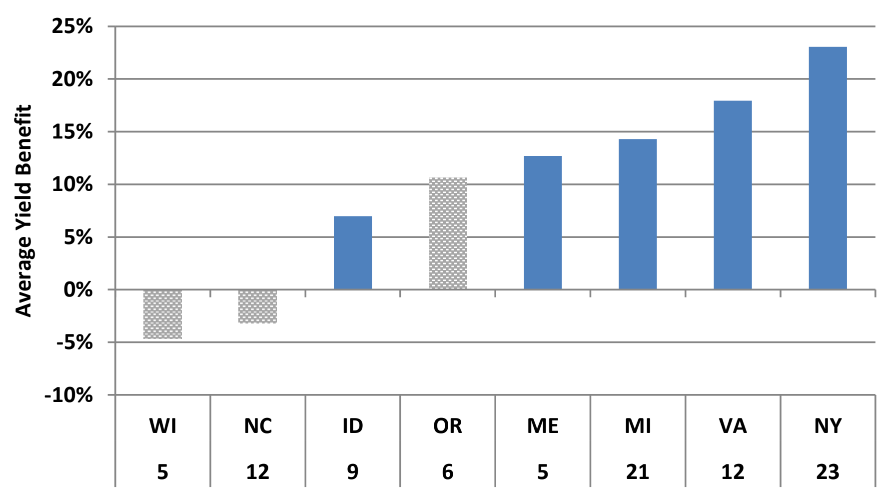
Potato Figure 4. Sorted bar graph of observed potato yield benefits for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments, truncated at −30% (N = 109, minimum = −34.06%, maximum = 119.00%, average = 12.64%, standard deviation = 22.72%, t = 5.810, p = <0.0001).



Potato Figure 5. Average potato yield benefit for neonicotinoid treatments relative to untreated control treatments by state (only states with at least 5 observations; number of observations below each state abbreviation; insignificant (p > 0.05) averages in hatched gray).



Potato Figure 6. Average potato yield benefit for neonicotinoid treatments relative to non-neonicotinoid insecticide treatments by state (only states with at least 5 observations; number of observations below each state abbreviation; insignificant (p > 0.05) averages in hatched gray).



Tomato Table 1. Sample statistics for the tomato yield benefit by data source for neonicotinoid treatments relative to untreated control treatments.

Source	No. of Studies	No. of Obs.	Average	Standard Deviation	t statistic	p value
Publications AMT	22	63	23.2%*	40.1%	4.586	<0.0001
Total	**22**	**63**	**23.2%***	**40.1%**	**4.586**	**<0.0001**

*Significant at 5% level.

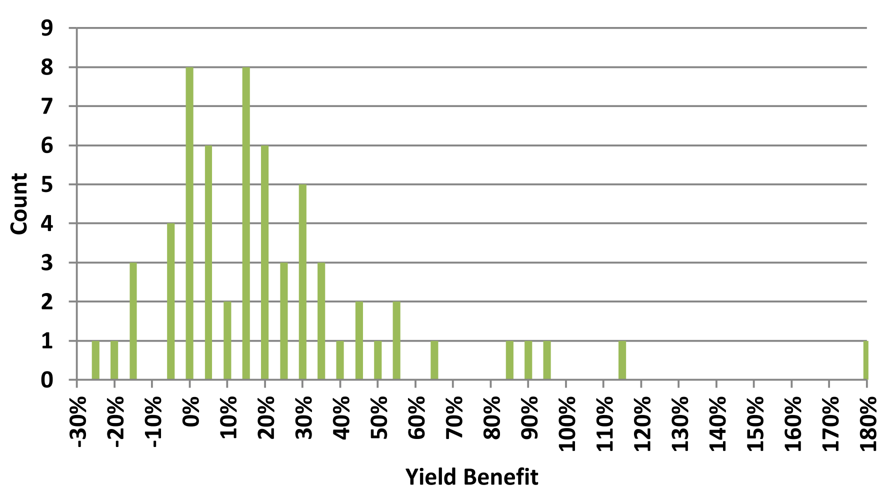
Tomato Table 2. Table not applicable, as no data were analyzed.

Tomato Table 3. Sample statistics for the tomato yield benefit by state/province for neonicotinoid treatments relative to untreated control treatments.

State/Province Abbreviation	No. of Obs.	Average	Standard Deviation	t statistic	p value
FL	56	22.2%*	41.3%*	4.017	0.0001
NC	2	13.3%	12.1%	1.557	0.1817
VA	5	38.0%*	32.3%*	2.631	0.0291
ALL	**63**	**23.2%***	**40.1%***	**4.586**	**<0.0001**

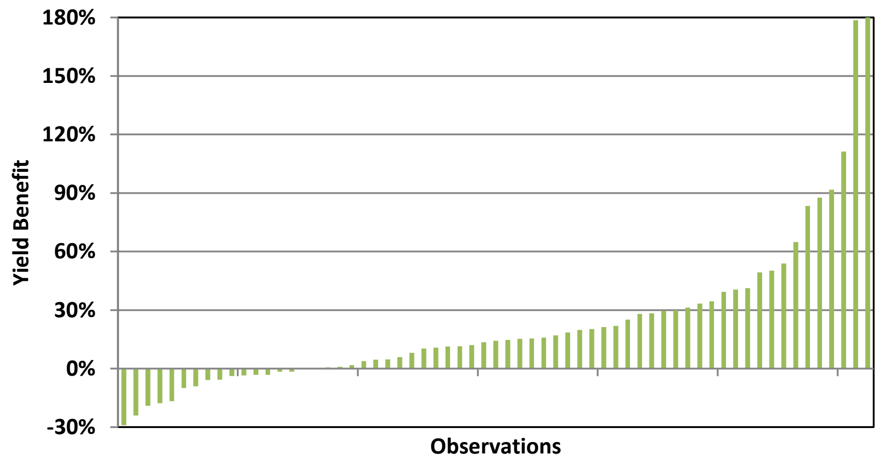
*Significant at 5% level.

Tomato Table 4. Table not applicable, as no data were analyzed.



Tomato Figure 1. Histogram of tomato yield benefits for neonicotinoid treatments relative to untreated control treatment, truncated at +180% (N = 63, minimum = –28.99%, maximum = 185.90%, average = 23.15%, standard deviation = 40.06%, t = 4.586, p = <0.0001).

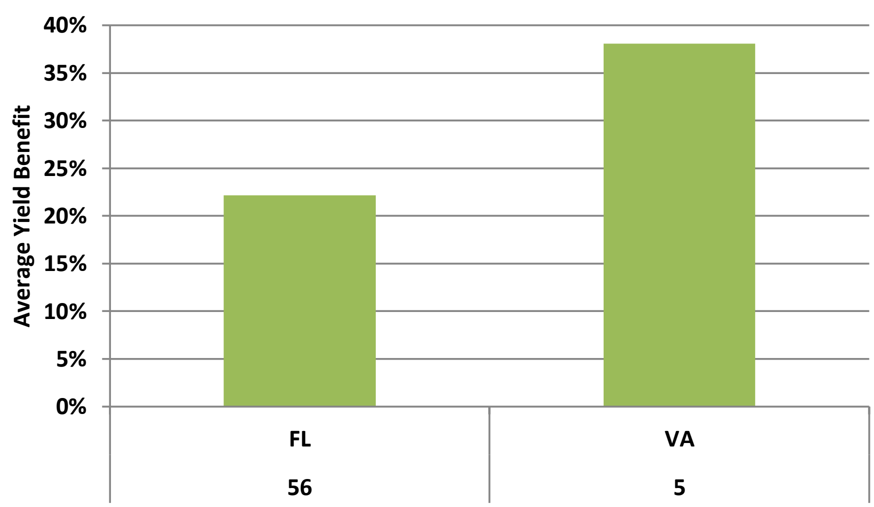
Tomato Figure 2. Sorted bar graph of observed tomato yield benefits for neonicotinoid treatments relative to untreated control treatments, truncated at +180% (N = 63, minimum = –28.99%, maximum = 185.90%, average = 23.15%, standard deviation = 40.06%, t = 4.586, p = <0.0001).



Tomato Figure 3. Figure not applicable, as no data were analyzed.

Tomato Figure 4. Figure not applicable, as no data were analyzed.

Tomato Figure 5. Average tomato yield benefit for neonicotinoid treatments relative to untreated control treatments by state/province (only states/provinces with at least 5 observations; number of observations below each state/province abbreviation; insignificant (p > 0.05) averages in hatched gray).



Tomato Figure 6. Figure not applicable, as no data were analyzed.

7.0 Appendix of Data References by Crop

Below are references by crop for the studies used for the meta-analysis. These are all the references other than those from *Arthropod Management Tests* (AMT). Note that no references are provided for potato or tomato since only studies published in AMT were used.

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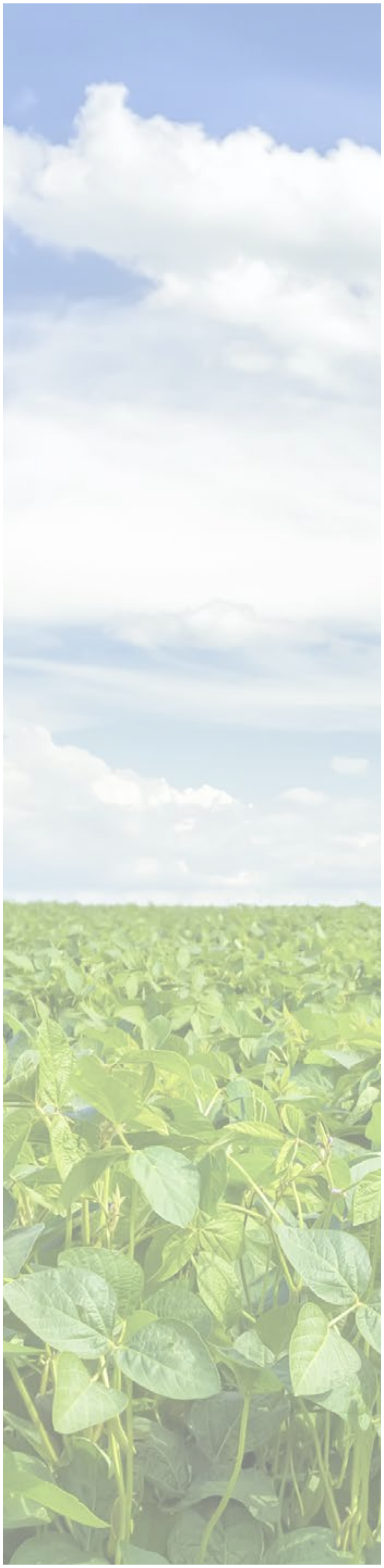

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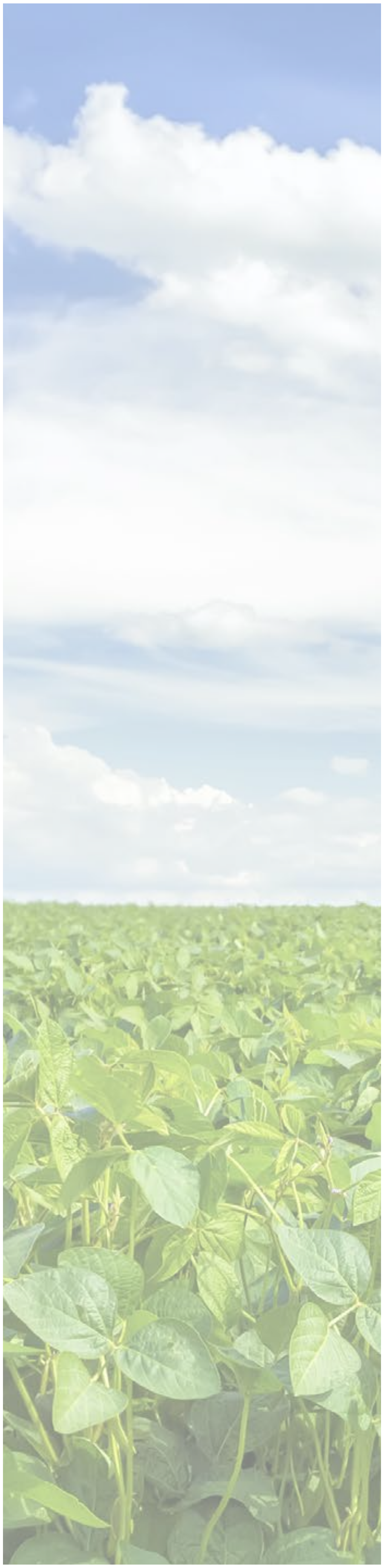

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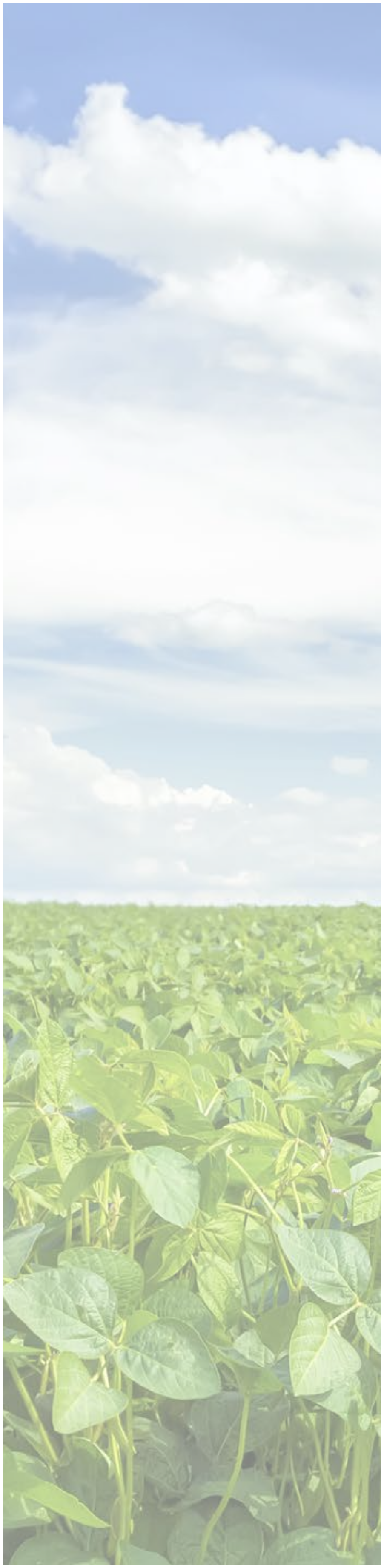

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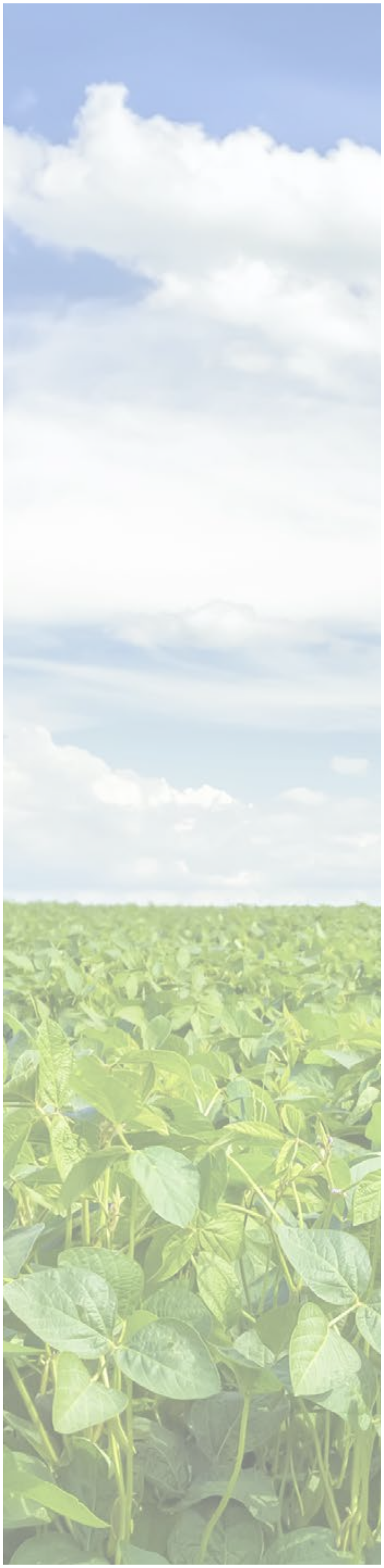

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