Technical Report:

Environmental Risk of Pesticide Use in Ontario: 2013/2014 Pesticide Use Survey.

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5 October 2016

Executive summary:

The objective of this study was to evaluate environmental risk of pesticides used in Ontario in 2013 and 2014. The 2013/2014 pesticide use survey (Farm & Food Care Ontario 2015) provided information on the amount pesticides applied and the Environmental Impact Quotient (EIQ) (Kovach et al. 1992) was used to quantify potential hazard. The EIQ values of over 100 pesticides were obtained (Eshenaur et al. 2015) and multiplied by the amount applied in kg active ingredient (a.i.) to obtain environmental impact (EI). The EI value is a measure of environmental risk, where the higher the EI value, the higher the risk.

Although pesticide use in Ontario increased over the decade, the risk increased at a slower rate. This trend was true for the grand total pesticide as well as herbicides. Growers applied a greater amount of pesticides; they used less hazardous pesticides (lower EIQ values). From 2008 to 2013/2014, fungicide use increased slightly (8.5%) but there was a slight decrease in environmental risk (-3.3% in environmental impact). From 2008 to 2013/2014, insecticide use decreased by 46% and the risk was lower by 68%. As well, the most hazardous pesticides are no longer used, thereby lowering overall risk. Although there may be an opportunity to lower pesticide use, it is encouraging that growers are using products with lower hazard.

Introduction

Based on personal experience and knowledge, an individual's perception of risk is often skewed higher or lower than the actual scientific probability of harm. Something that can cause harm (electricity, stress, chemicals) is called a hazard; whereas, risk is the probability or chance (high or low) that harm will actually occur. For instance, the most toxic compound known is botulinum toxin (causes lethal botulism) is very hazardous. However due to proper sterilization and food preparation, there is very little exposure to the toxin and thus the actual risk of harm is very low (i.e. very few people suffer from botulism).

The same principle of hazard and risk applies to pesticides. The Environmental Impact Quotient (EIQ) is an indication of hazard, and the calculated environmental impact (EI) is an indicator of risk. The EIQ developed by Kovach et al. (1992) is designed to provide growers and other decision makers with one value for each pesticide that indicates the magnitude of relative hazard/risk; the higher the EIQ or EI number, the higher the hazard or risk, respectively.

The EIQ estimates the hazard of pesticide active ingredients to farm workers, consumers, and ecosystems. However, the EIQ is only one part of determining the overall risk because one also needs to consider the amount of the pesticide used. For instance, if a pesticide has a high EIQ but isn't used at all, then the risk is zero. Thus, the EIQ value for a pesticide is multiplied by the amount used to determine the environmental impact (EI) of pesticide use.

The EIQ is a measure of hazard and environmental impact is a measure of risk. Overall, a higher EI value indicates a greater overall risk compared to another product. By using lower pesticide rates and/or safer products (i.e., those with lower EIQ values), the risk of pest control may be reduced. Therefore, evaluations and decisions should be made based on EI values.

The objective of this work was to assess the risk of pesticide use in Ontario based on the 2013/2014 pesticide use survey (Farm & Food Care Ontario 2015) and to compare to previous years (2003 and 2008).

Methods

There are other measurements of environmental risk of pesticide use (Peterson 2010). The use of EIQ has been debated in the literature (Kniss and Coburn 2015; Peterson and Schleier 2014; Gallivan et al. 2010). However, assessments of pesticide applications still use EIQ for scientific and policy purposes (Bahlai et al. 2010; Cross and Edwards-Jones 2006; Peck et al. 2010; Soltani et al. 2010, 2012; Steward et al. 2011) and Gallivan et al. (2010) used it for previous Ontario pesticide use surveys.

The 2013/2014 pesticide risk assessment was conducted with similar methods as previous Ontario studies (Gallivan et al. 2008). The pesticide assessment was conducted using the EIQ developed by Kovach et al. (1992) with updated EIQ values which are available online by Eshenaur et al. (2015). The EIQ value of a pesticide was calculated as the impact to farmers, consumers and ecosystems using the following formula:

$$EIQ = (farmer + consumer + ecological)/3$$

Where each component is calculated as follows:

$$EIQ=\{C[(DT*5)+(DT*P)]+[(C*((S+P)/2)*SY)+(L)]+[(F*R)+(D*((S+P)/2)*3)+(Z*P*3)+(B*P*5)]\}/3$$

where:
C = chronic toxicity (reproductive, developmental, genotoxicity and carcinogenicity)
DT = dermal toxicity (acute rat/rabbit dermal LD_{50})
P = plant surface half-life (weeks)
S = soil half-life (days)
SY = systemicity (mode of action and systemic absorption in plants)
L = leaching potential
F = fish toxicity (96-hr LC_{50})
R = runoff potential
D = bird toxicity (8-day LC_{50})
Z = bee toxicity
B = beneficial arthropod toxicity

The higher the EIQ value, the higher the hazard of the pesticide. However, all estimates of risk require a measure of exposure. Thus to obtain a measure of risk, the EIQ is multiplied by the quantity applied expressed as kg active ingredient (a.i.) to measure environmental impact (EI).

$$\text{Environmental Impact (EI)} = EIQ \times \text{kg a.i.}$$

The results from the survey of pesticide use in Ontario in 2013/2014 (Farm & Food Care Ontario 2015) were used to obtain the amount pesticide a.i. applied. The overall risk of pesticides used in the province was the sum of individual pesticide EI values. Similar to previous Ontario pesticide surveys, ‘grand total’ represents all pesticides reported and ‘total’ represents sum of herbicides, insecticides, fungicides (the three major types of pesticides). Sums of each pesticide type were included to look at overall effect of herbicides, insecticides and fungicides used in the province. Due to their low use, some pesticides in the survey were classified as ‘other’. In all cases, the contribution of ‘other’ pesticides was relatively small at approximately 1.9% (insecticides) to 0.06% (herbicides) of the total EI. For these instances, the average EIQ for each pesticide type was used to estimate contribution of ‘other’ pesticides to risk.

When the EIQ value was not available via Eshenaur et al. (2015), other published values were used such as pyrasulfotole (EIQ=35.3) (Van Eerd calculated for WeedPro, Cowbrough et al. 2007); thifensulfuron-methyl (EIQ=29.17) (Soltani et al. 2010). The following fungicides did not have published EIQ values and were not included in the EI calculation: fluopyram, fluxapyroxad, prothioconazole, penthiopyrad and reynoutria sachalinensis (organic fungicide, an extract of giant knotweed). These fungicides represent 2.4% of all fungicides used in Ontario as reported in the 2013/2014 survey (Farm & Food Care Ontario 2015). Using an EIQ of 26.7, the average EIQ of all fungicides, this would amount to 2.5% of all fungicide EI. Thus, it is reasonable to assume the absence of these pesticides in the calculation had little impact on interpretation of EI, which is similar to that assumed by Peck et al. (2010).

Other modifications were required to accommodate for how pesticides were reported in the survey and/or the EIQ values available. They included the following: a) MCPA/MCPB was the average EIQ of each active ingredient. b) The EIQ for Bordeaux mix (copper sulfate and lime) was used for copper sulfate. c) Potassium salts were the average values of potassium bromide and potassium bicarbonate.

There were differences in EIQ values published by Gallivan et al. (2001, 2010) compared to those provided by Kovach et al. (2012) and Eshenaur et al. (2015) that were used in this study. For instance, the current EIQ values (Eshenaur et al. 2015) were 16 to 65% lower than those used and reported by Gallivan et al. (2001; 2010). The reason for this change is not known but could be due to more information available on the parameters used in the EIQ calculations. For instance, Gallivan et al. (2010) used a modified EIQ (mEIQ) that was based on quantified plant surface half-life as opposed with the default value of 3 (options of 1 to 5). However, this alone does not explain the vast difference in EIQ values. Thus, caution should be used when comparing EIQ and EI values reported here to those of Gallivan et al. (2001, 2010 and others) as different (often higher) EIQ values were previously used. For this report, updated EIQ values (Eshenaur et al. 2015) were used in this study to facilitate comparison in the future. Also, all comparisons among years (2003, 2008, and 2013/2014) were done using current EIQ values (Eshenaur et al. 2015), unless stated elsewise.

To compare between years, pesticide survey data from the 2003 (McGee et al. 2004) and 2008 (McGee et al. 2010) reports were used to recalculate EI values using the currently available EIQ values (Eshenaur et al. 2015). Thus, for this study, trends in the risk of pesticide use in 2013/2014 were compared to (i) the last survey year 2008, (ii) the 2003 pesticide survey used for Food Systems 2002, and (iii) 1983 and 1998 pesticide survey data from Gallivan et al. (2001). The 1983 survey was the benchmark year of the Food Systems 2002 program and 1998 was the latest year reported in Gallivan et al. (2001). Food Systems 2002 was an Ontario government initiative to reduce pesticide use by 50% (see Gallivan et al. 2010).

The most direct and meaningful data comparisons were 2013/2014 to 2008 and 2003. Data were expressed as a percent to show increase/decrease of EI values in 2013/2014 relative to 2003, which was calculated as = $(EI_{2013} – EI_{2003})/EI_{2003}x100$. The same calculation was made for comparisons of 2013/2014 to 2008. However, caution should be used with the 2013/2014 pesticide use survey due to comparatively low grower survey responses in 2013/2014 compared to previous years (475 vs. > 1200) (Farm & Food Care Ontario 2015). Due to the low survey responses, the risk for each crop or county were not analyzed. A higher response rate with good representation of each crop and area would provide a more accurate provincial estimate of pesticide use and environmental impact.

Results and Discussion:

Over the past thirty years in Ontario, there has been a 38% reduction in pesticide use. Some of the most hazardous pesticides are no longer used in the province.

Trends from 2003, 2008 to 2013/2014

As summarized by Farm & Food Care Ontario (2015), pesticide use increase from 4.22 to 4.87 to 5.4 ($x10^6$) in grand total (all reported) from 2003 to 2008 to 2013/2014, respectively (Table 1); but the rate of increase slowed from 2008 to 2013/2014. For the grand total pesticide, EI values increased from 87, 100, and 103 ($x 10^6$) in 2003, 2008 and 2013/2014, respectively (Table 1). Thus, there was only a 2% increase in EI from 2008 to 2013/2014, while pesticide use changed by 11%. Over time, the risk of pesticides did not increase at the same rate as grand total pesticide use, which indicates that farmers are choosing to apply less hazardous pesticides.

It is worthwhile characterizing other categories of growth regulators and nematicides (Table 1). Similar to reported use, in 2003, 2008 and 2013/2014, both growth regulators and nematicides accounted for 12%, 7% and 0.6%, respectively, of the total EI of all pesticides reported. Trends over time with growth regulators product use and risk were not easily deciphered due to differences among years. In the 2013/2014 survey results, carbaryl was correctly categorized as a growth regulator, based on its use in orchards as a fruit thinner. But, carbaryl has been used for that purpose by growers for decades but was not categorized in this way in previous reports. Therefore, the differences observed among previous years may not be a true reflection of grower trends in pesticide use; hence, it is not possible to compare carbaryl use among years. Growth regulator use of carbaryl was less than 0.1% of insecticide use in 2013/2014. Therefore, there is little effect on the interpretation of insecticide use over time. Nematicides were not reported in 2013/2014; likely a reflection of the discontinuation of registration of some product, new mitigation measures and low survey response numbers. Overall, growth regulators and nematicides accounted for less than 0.5% of pesticide use and EI values in 2013/2014. Due to low contribution of growth regulators and nematicides to grand total, this study focused on herbicides, fungicides and insecticides and their total (referred to as total pesticide).

Trends in total pesticide (the sum of herbicides, fungicides and insecticides) risk shows an increase in 2013/2014 compared to the previous decade. In 2013, the overall EI was 102 $x10^6$, which was higher than 2003 (EI=76.4 $x10^6$) and 2008 (EI=93 $x10^6$) (Table 1). Although total pesticide use increased by 18%, EI increased by 10% from 2008 to 2013/2014. Thus, the increase in risk was almost half as use. It is also important to note, that total pesticide use and EI values in 2013/2014 was considerably lower than 1983 and 1998 (Gallivan et al. 2001). Moreover, the rate of increase in pesticide risk of total pesticides slowed in the past 5 years and the rate of increase was slower for EI than total pesticide use. When comparing the 2013/2014 results to 2003 and 2008 for total pesticide use, there was a 44% and 18% increase, respectively (Fig. 1). The total EI values from 2013/2014 showed an increase as well by 34% and 10% respectively, when compared to 2008 and 2003; however, the percent change in pesticide risk was not as great as that calculated for use (Fig. 1). This is mainly due to growers using less hazardous (lower EIQ) total pesticides in 2013/2014. Average EIQ of total pesticides was 27 in 2003 which decreased to 25.5 and 25.2 in 2008 and 2013/2014, respectively (Table 1). Factors contributing to changes in pesticide risk are those influencing pesticide use as described by Farm and Food Care Ontario (2015) and include changes in crop acreage, discontinuation of pesticide registration, pest outbreaks, introduced pest, pest resistance to pesticides, and weather in the reporting year.

Herbicides

The number of herbicide active ingredients report decreased over time (Table 1). There were 17% and 14% fewer herbicide active ingredients reportedly used in 2013/2014 compared to 2003 and 2008, respectively (Table 1). But there was very little change in average EIQ values over time (i.e. 21.4, 21.8, 22.3) (Table 1). Over the decade, there was an increase in the amount of herbicides used and their risk. Herbicide use increased by 36% and 21% in 2013/2014 compared to 2003 and 2008, respectively (Fig. 1). Table 1, Figure 1). However, risk did not increase as rapidly as pesticide use; with an increase in the EI values of 25% from 2003 to 2013/2014 and 18% from 2008 to 2013/2014 (Fig. 1). Herbicide EI values increased from 64.6 to 68.7 to 80.8 (x 10^6) over the decade (Table 1). Lower percent change over time suggests that growers were using herbicides with lower hazard (i.e. lower EIQ) in 2013/2014 than the previous two surveys (Table 1, 2).

Fungicides

The substantial increase in fungicides use and risk from 2003 to 2008 (Fig. 1). The reason for this shift is not captured in the pesticide use survey. Possible explanations include shifts in commodity acreage and crop prices, changes in tillage practices, new introductions or emerging pest/disease issues, weather conditions that are conducive to certain diseases or pests, promotion of fungicide use for improved plant health, resistance development, challenges in monitoring for certain pests and diseases, difficulties in the development of economic thresholds for certain pests and diseases and the observed variable yield response to foliar fungicide use for plant health maintenance in the absence of disease presence. It is important to note that there was little change in fungicide use from 2008 to 2013/2014 and a decrease in risk. The average fungicide EIQ decreased over time; 30.6 in 2003, 27.7 in 2008 and 26.8 in 2013/2014 (Table 1). There was a greater than 2-fold increase in fungicide use and risk during the decade (Table 1). Most of the increase occurred by 2008. In 2013/2014, total fungicide EI value was 20.5 x 10^6, which was lower than 2008 (21.2 x 10^6) From 2008 to 2013/2014, there was very little change in fungicide use (8.5%) and EI values (-3.3%) (Table 1, Fig. 1). Thus over the most recent 5 years, fungicide risk decreased.

Insecticides

Over time, the risk from insecticide use decreased. The total EI value of insecticide use was 1.1 x 10^6 in 2013/14 which was a decrease of 58% and 63% compared to 2003 and 2008 (Table 1; Fig. 1). Insecticide use decreased by 30% to 46% compared to 2003 and 2008, respectively (Fig. 1). Hence, the risk decreased more rapidly than use. This was due to growers using less hazardous products. Average insecticide EIQ decreased over time; 35.2, 30.2 and 29.7 for 2003, 2008 and 2013/2014, respectively (Table 1). The lower average insecticide EIQ over time is due to the phase out of those with high hazard, such as parathion (EIQ= 69.6) and terbufos (66.0) (Table 2). Similar to herbicides and fungicides, growers were using insecticides with lower hazard in 2013/2014 than previous years. The decrease in insecticide use may be due, in part, to previously invasive insect pests (such as soybean aphids) becoming endemic, where natural enemies are better able to respond to infestations than when the pests first arrived in Ontario. The decrease in insecticide use and risk may also be due, in part, to insecticide seed treatments that protect the crop from early season insect pests. Seed treatments use has not, to date, been captured in the pesticide use survey, due in part to these products being applied to seed through commercial seed treatment facilities and not by the farmer. Overall, in 2013/2014 both insecticide use and risk was lower than the two previous surveys. This is particularly important because the average EIQ for insecticides was higher than fungicides and herbicides (Table 1).

Top Ten Pesticides

Top Ten Most Hazardous Pesticides. One way to evaluate change in pesticide risk over time is to look at the top ten most hazardous (i.e., the highest EIQ values) pesticides used. In 2013/2014, the top ten most hazardous used pesticides were mainly fungicides (60%) (Table 2). This list was in contrast to the previous surveys, where 80% and 50% were insecticides in 2003 and 2008, respectively. The change from insecticides to fungicides was due primarily to the phasing out of hazardous insecticides. For instance, diazinon (listed in each survey year) is being phased-out by the Pest Management Regulatory Agency (PMRA 2013). Two hazardous pesticides used in 2013/2014 were copper fungicides (EIQ=54.3-61.9) and streptomycin sulphate (EIQ=45). Based on current trends and re-evaluations by the PMRA, one would expect the average EIQ to decrease over time.

Gallivan et al. (2001) published the top ten pesticides with the highest EIQ used in 1983 and 1998. Only 2 of the 10 pesticides from 1983 were still reportedly used in 2013/2014. Compared to 2003, only 3 out of the top ten highest EIQ pesticides were used in 2013/2014 (Table 2). Hence, by 2013/2014 very few of the most hazardous pesticides were still in use, which indicates that growers are using less hazardous pesticides now compared to one and two decades ago. To allow direct comparison between years, updated EIQ values (Eshenaur et al. 2015) were used to compare the top ten hazardous pesticides used. The top ten pesticides had average EIQ values of 54.5 in 1983, 52.6 in 2003, 46.5 in 2003, and 44.3 in 2013/2014. Clearly, over time, growers are using pesticides with lower hazard.

Top Ten Most Used Pesticides. Glyphosate was the most used pesticide in all three survey years. It represented 40% to 60% of the kg applied from the top ten list (Table 3). The high glyphosate use was due to high acreage of glyphosate-tolerant crops (corn, soybeans, sugarbeets) and its use as a weed burndown and crop desiccant as well as use in various tillage systems such as conventional tillage, conservation tillage and no-till systems (See Farm and Food Care Ontario 2015 for more information) Another trend was the increase in fungicide use over time, from none in the top ten list in 2003 to 50% and 30% in 2008 and 2013/2014, respectively. From this top ten listed (Table 3) fungicides tended to have higher hazard with average EIQ values of 26.3 to 30.4 compared to herbicides of <22.

Top Ten Pesticides with Greatest Risk (highest EI values). Ultimately, it is risk that is the focus of this report. In 2013/2014, only one pesticide in the top ten list, chloropicrin, had a relatively high hazard (EIQ value above 40) (Table 4), which indicates that use rather than hazard is the biggest contributing factor. For instance, the hazard of glyphosate is quite low (it is on the top ten pesticides with the *lowest* hazard as indicated by EIQ values (Table 5)). But due to its comparatively high use (Table 3), glyphosate has the greatest risk (Table 4). The average EIQ value of the top ten with the greatest risk was 26.2 in 2013/2014 and did not change from 2008, suggesting no change in hazard from the pesticides listed in this top ten. Keep in mind, that risk can only be lowered by selecting less hazardous pesticides and/or by applying less pesticides.

Further Discussion

Changes in land use and agricultural crop trends provide a possible explanation of differences in risk between 2003 and 2013/2014. Perhaps the most influential was the conversion of range/pastureland to grain crops. Smith (2015) reported a decline in hay and pasture land and an increase in soybeans and corn during that 2003 to 2011. There is a greater need for pesticide use with grain crops than in pasture due to more pest and disease pressure during the growing season (for instance, risk of mycotoxins in corn grown for livestock feed), and greater need for weed control during seedbed and crop establishment. See Farm and Food Care Ontario (2015) report of Survey of Pesticide Use in Ontario, 2013/2014 for more discussion of trends in pesticide use.

Farmers are using fewer pesticide active ingredients (Table 1). From 2003 to 2013/2014 there was decease in the number of active ingredients reported from 53 to 44 herbicides (a 17% reduction) and 25 to 19 insecticides (a 24% reduction). This represents a significant decline. The decrease in the number pesticides used was likely due to discontinuation of registration of some active ingredients. Or it is possible that growers are just choosing to use fewer different pesticides. Regardless of the reason, having fewer pesticides available for pest management may be a concern, particularly for pesticide resistance management.

It is recommended that the pesticide use survey continue to be conducted every 5 years. It is unlikely that a change in the frequency of surveys would be necessary. One must consider that pesticide use greatly depends on weather conditions in any given year. Wet years favour disease and fungicide use. Abnormally dry or wet conditions many necessitate more herbicide applications. Insect pressure is also influenced not only by weather conditions during the growing season but also on previous years' conditions (ie. the severity of temperatures in the previous winter to disrupt pest reproduction cycles). Thus while a survey every 5 years is sufficient, one cannot ignore the influence of weather on pesticide use and its impact on interpretation of patterns of pesticide risk.

Unfortunately, the number of growers who responded to the pesticide use survey was low; approximately 1/3 of previous years (450 vs. 1300). There is confidence that survey data were representative of the whole province; more confidence would have been conferred with a higher survey response rate. In the future, efforts should focus on gaining participation of more growers.

Conclusions:

Reported total pesticide use increased from 2003 to 2008 and from 2008 to 2013/2014. Likewise, pesticide risk increased as indicated by EI values. However, the rate of increase of pesticide risk was lower than use. This means that although growers applied a greater amount of pesticides, they used pesticides with lower hazard (lower EIQ values). This trend was true for the grand total pesticide as well as herbicides. From 2008 to 2013/2014, fungicide use increased slightly (8.5%) but there was a slight decrease in environmental risk (-3.3% in environmental impact). Most notability, there was a decrease in insecticide use and risk over time. While there may be an opportunity to lower pesticide use, it is encouraging that growers are using products with lower hazard, which results in lower environmental risk.

References:

Bahlai, C.A., Y. Xue, C.M. McCreary, A.W. Schaafsma, and R.H. Hallett. 2010. Choosing Organic Pesticides over Synthetic Pesticides May Not Effectively Mitigate Environmental Risk in Soybeans. PlosONE 5: e11250

Cross, P. and G. Edwards-Jones. 2006. Variation in pesticide hazard from arable crop production in Great Britain from 1992 to 2002: Pesticide risk indices and policy analysis. Crop Protection 25:1101–1108

Farm & Food Care Ontario. 2015. Survey of Pesticide Use in Ontario, 2013/2014.Estimates of Pesticides Used on Field Crops and Fruit and Vegetable Crops. Prepared by Farm & Food Care Ontario November 2015. 20 pp.

Gallivan, G.J., G.A. Surgeoner and J. Kovach. 2001. Pesticide risk reduction on crops in the Province of Ontario. Journal of Environmental Quality 30: 798-813.

Gallivan, G.J., D. Beaton, B. McGee and H. Berges. 2010. Survey of Pesticide Use and Evaluation of the Changes in Pesticide Risk on Agricultural Crops in Ontario in 2008. New Directions Report. 48 pp.

Eshenaur, B., Grant, J., Kovach, J., Petzoldt, C., Degni, J., and Tette, J. 2015. www.nysipm.cornell.edu/publications/EIQ. Environmental Impact Quotient: "A Method to Measure the Environmental Impact of Pesticides." New York State Integrated Pest Management Program, Cornell Cooperative Extension, Cornell University. 1992 – 2015.

Kniss, A.R. and C.W. Coburn. 2015. Quantitative Evaluation of the Environmental Impact Quotient (EIQ) for Comparing Herbicides. PLoS ONE 10(6): e0131200. doi:10.1371/journal.pone.0131200.

Kovach, J., C. Petzoldt, J. Degni and Tette, J. 1992. A method to measure the environmental impact of pesticides. New York's Food and Life Sciences Bulletin 139: 1-8.

McGee, B., H. Berges and K. Callow. 2004. Survey of pesticide use in Ontario, 2003. Estimates of pesticides used on field crops, fruit and vegetable crops, and other agricultural crops. Ontario Ministry of Agriculture and Food, Policy and Programs Branch, Economics Information Report, 18 pp.

McGee, B., H. Berges and D. Beaton. 2010. Economics Information - Survey of Pesticide Use in Ontario, 2008 Estimates of Pesticides Used on Field Crops, Fruit and Vegetable Crops, and Other Agricultural Crops. Ontario Ministry of Agriculture, Food and Rural Affairs. Pp 18. ISBN 978-1-4435-3357-7

Peck, G.M., I.A. Merwin, M.G. Brown, and A.M. Agnello. 2010. Integrated and Organic Fruit Production Systems for 'Liberty' Apple in the Northeast United States: A Systems-based Evaluation. HORTSCIENCE 45:1038–1048.

Peterson, R.K.D. 2006. Comparing ecological risks of pesticides: the utility of a Risk Quotient ranking approach across refinements of exposure. Pest Manag. Sci 62:46–56.

Peterson, R.K.D. and J.J. Schleier III. 2014. A probabilistic analysis reveals fundamental limitations with the environmental impact quotient and similar systems for rating pesticide risks PeerJ 2:e364; DOI 10.7717/peerj.364.

PMRA. 2013. Re-evaluation Note REV2013-01, Diazinon Risk Management Plan Pest Management Regulatory Agency. 18 June 2013 ISSN: 1925-0649. Catalogue number: H113-5/2013-01E-PDF. Available: http://www.hc-sc.gc.ca/cps-spc/pubs/pest/_decisions/rev2013-01/index-eng.php

Smith, P.G. 2015. Long-Term Temporal Trends in Agri-Environment and Agricultural Land Use in Ontario, Canada: Transformation, Transition and Significance. Journal of Geography and Geology. 7(2): doi:10.5539/jgg.v7n2p32

Soltani, N., R.E. Nurse, L.L. Van Eerd, R.J. Vyn, C. Shropshire, and P.H. Sikkema. 2010. Weed control, environmental impact and profitability with trifluralin plus reduced doses of imazethapyr in dry bean. Crop Protection. 29:364-368.

Soltani, N., Stewart, C.L., R.E. Nurse, L.L. Van Eerd, R. J. Vyn, and P.H. Sikkema. 2012. Weed Control, Environmental Impact and Profitability of Weed Management Strategies in Glyphosate-Tolerant Corn. American Journal of Plant Sciences. 3:1594-1607.

Stewart, C.L., R.E. Nurse, L.L. Van Eerd, R.J. Vyn, and P.H. Sikkema. 2011. Weed Control, Environmental Impact and Profitability of Weed Management Strategies in Glyphosate-Resistant Soybean. Weed Technology. 25:535–541.

Table 1. Summary of all reported pesticide used in Ontario with environmental impact (EI) quotient (EIQ) in 2003, 2008 and 2013/2014.

Parameter	Herbicide	Fungicide	Insecticide	Total	Growth Regulator	Nematicide	GRAND TOTAL
				2003			
Number of a.i.*	53	26	25	104	4	5	113
Average EIQ	21.4	30.6	35.2	27.0	24.8	32.3	
EI ($x10^6$)	64.6	9.12	2.73	76.4	0.0721	10.3	86.9
Amount used (kg $x10^6$)	3.35	0.314	0.0818	3.74	0.142	0.332	4.22
EIQ/EI data unavailable		Antimycin			fatty acids/ alcohols	methyl isothiocyanate	
				2008			
Number of a.i.	51	35	27	113	4	3	120
Average EIQ	21.8	27.7	30.2	25.5	19.8	32.3	
EI ($x10^6$)	68.7	21.2	3.11	93.1	0.107	7.25	100
Amount used (kg $x10^6$)	3.78	0.714	0.106	4.59	0.0245	0.247	4.87
EIQ/EI data unavailable	phenmedi-pham	lime sulphur / calcium polysulphide, ferric dimethylidithio-carbamatte, prothioconazole			fatty acids/ alcohols		
				2013			
Number of a.i.	44	37	19	100	3	0	103
Average EIQ	22.3	26.8	29.7	25.2	23.7	-	
EI ($x10^6$)	80.8	20.5	1.16	102	0.126	-	103
Amount used (kg $x10^6$)	4.56	0.775	0.0575	5.40	0.0061	-	5.40
EIQ/EI data unavailable		fluopyram, fluxapyroxad, prothioconazole, reynoutria sachalinensis			6-benzyl-adenine		

*a.i., active ingredients

Table 2. Pesticides† with the 10 highest hazard indicated by **environmental impact (EI) quotient (EIQ)** values in 2003, 2008, and 2013/2014.

Pesticide Used	Type‡	EIQ	EI (x1000)	Amount used (kg x1000)
		2003		
parathion	i	69.6	14.7	0.211
terbufos	i	66.0	114	1.73
copper (metalic/ sulfphate/oxychloride)	f	54.3-61.9	674	12.3
azinphos-methyl	i	53.0	525	9.90
carbofuran	i	50.7	90.1	1.78
cypermethrin	i	50.7	91.7	1.81
naled	i	49.2	15.5	0.315
flusilazole	f	45.9	54.5	1.19
lambda-cyhalothrin	i	44.2	12.0	0.271
diazinon	i	44.0	175	3.97
EIQ AVE + TOTALS		52.6	1,767	33.5
		2008		
copper (sulfphate/ oxychloride)	f	54.3-61.9	582	10.3
azinphos-methyl	i	53.0	80.8	1.52
carbofuran	i	50.7	33.1	0.654
cypermethrin	i	50.7	103	2.04
dinocap	f	46.5	72.3	1.55
streptomycin sulphate	f	45.0	14.9	0.332
lambda-cyhalothrin	i	44.2	50.0	1.13
diazinon	i	44.0	351	7.98
fenoxaprop-p-ethyl	h	43.7	22.2	0.509
metiram	f	40.6	3,590	88.4
EIQ AVE + TOTALS		46.5	4,900	114
		2013/2014		
copper sulphate	f	61.9	49.9	0.806
streptomycin sulphate	f	45.0	15.9	0.352
lambda-cyhalothrin	i	44.2	16.2	0.368
diazinon	i	44.0	194	4.42
fenoxaprop-p-ethyl	h	43.7	18.1	0.415
chloropicrin	fum	42.4	2,080	49.1
difenoconazole	f	41.5	77.4	1.87
metiram	f	40.6	250	6.15
tebuconazole	f	40.3	357	8.84
diquat	h	39.2	204	5.20
EIQ AVE + TOTALS		44.3	3,270	77.5

†does not include growth regulators nor nematicides
‡f, fungicides; h, herbicides; i, insecticides; fum, fumigant

Table 3. The top 10 most **used** pesticides† reported in 2003, 2008, and 2013/2014.

Pesticide Used	Type‡	EIQ	EI (x10^6)	Amount (kg x10^6)
		2003		
glyphosate	h	15.3	17.9	1.17
atrazine	h	22.8	11.7	0.514
s-metolachlor	h	22.0	6.31	0.287
metolachlor	h	22.0	5.63	0.256
dimethenamid-P	h	12.0	2.47	0.205
dicamba	h	26.3	5.15	0.196
MCPA/MCPB	h	23.5	3.04	0.129
2,4-D amines	h	16.7	1.45	0.0873
pendimethalin	h	30.2	2.57	0.0853
bromoxynil	h	17.0	1.37	0.0809
EIQ AVE + TOTALS		20.8	57.7	3.01
		2008		
glyphosate	h	15.3	31.6	2.06
s-metolachlor	h	22.0	10.4	0.472
atrazine	h	22.8	10.5	0.460
sulphur	f	32.7	4.72	0.144
mancozeb	f	25.7	3.71	0.144
captan	f	15.8	1.86	0.118
chlorothalonil	f	37.4	4.19	0.112
MCPA/MCPB	h	23.5	2.53	0.108
metiram	f	40.6	3.59	0.0884
dicamba	h	26.3	2.08	0.0790
EIQ AVE + TOTALS		26.2	75.2	3.79
		2013/2014		
glyphosate	h	15.3	44.6	2.91
s-metolachlor	h	22.0	16.9	0.769
atrazine	h	22.8	6.80	0.298
mancozeb	f	25.7	6.59	0.256
chlorothalonil	f	37.4	3.72	0.099
metribuzin	h	28.4	2.58	0.091
captan	f	15.8	1.40	0.089
MCPA/MCPB	h	23.5	2.05	0.087
dimethenamid-P	h	12.0	0.753	0.063
bromoxynil	h	17.0	1.03	0.060
EIQ AVE + TOTALS		21.9	86.4	4.72

†does not include growth regulators nor nematicides

‡f, fungicides; h, herbicides

EIQ, Environmental impact quotient; EI, environmental impact.

Table 4. Pesticides† with the 10 highest risk as indicated by **environmental impact (EI)** in 2003, 2008, and 2013/2014.

Pesticide Used	Type‡	EIQ	EI ($x10^6$)	Amount (kg $x10^6$)
		2003		
glyphosate	H	15.3	17.9	1.17
atrazine	H	22.9	11.7	0.514
s-metolachlor	H	22.0	6.31	0.287
metolachlor	H	22.0	5.63	0.256
dicamba	H	26.3	5.15	0.196
MCPA/MCPB	H	23.5	3.04	0.129
pendimethalin	H	30.2	2.57	0.0853
dimethenamid-P	H	12.0	2.47	0.2053
sulphur	F	32.7	1.77	0.0541
mancozeb	F	25.7	1.66	0.0646
EIQ AVE + TOTALS		23.3	58.3	2.96
		2008		
glyphosate	H	15.3	31.6	2.06
atrazine	H	22.9	10.5	0.460
s-metolachlor	H	22.0	10.4	0.472
sulphur	F	32.7	4.72	0.144
chlorothalonil	F	37.4	4.19	0.112
mancozeb	F	25.7	3.71	0.144
metiram	F	40.6	3.59	0.0884
MCPA/MCPB	H	23.5	2.53	0.108
dicamba	H	26.3	2.08	0.0790
captan	F	15.8	1.86	0.118
EIQ AVE + TOTALS		26.2	75.2	3.79
		2013/2014		
glyphosate	H	15.3	44.6	2.91
s-metolachlor	H	22.0	16.9	0.769
atrazine	H	22.9	6.80	0.298
mancozeb	F	25.7	6.59	0.256
chlorothalonil	F	37.4	3.72	0.0993
metribuzin	H	28.4	2.58	0.0909
chloropicrin	Fum	42.4	2.08	0.0491
MCPA/MCPB	H	23.5	2.05	0.0874
sulphur	F	32.7	1.81	0.0554
captan	F	15.8	1.40	0.0889
EIQ AVE + TOTALS		26.6	88.5	4.70

†does not include growth regulators nor nematicides
‡F, fungicides; H, herbicides; Fum, Fumigant
EIQ, Environmental impact quotient.

Table 5. Pesticides† with the 10 **lowest** environmental impact (EI) quotient (EIQ) in 2003, 2008, and 2013/2014.

Pesticide Used	Type‡	EIQ	EI (x1000)	Amount (kg x 1000)
		2003		
EPTC/R25788	h	9.4	18.3	1.95
flufenacet	h	11.3	91.0	8.03
fosetyl-AL	f	12.0	64.5	5.37
dimethenamid-P	h	12.0	2,470	205
fenhexamid	f	12.4	3.59	0.290
napropamide	h	12.6	35.0	2.79
Bacillus thuringiensis	i	13.3	81.8	6.14
kresoxim-methyl	f	15.1	9.83	0.652
glyphosate	h	15.3	17,950	1170
mecoprop-p	h	15.3	10.8	0.703
EIQ AVE + TOTALS		12.9	20730	1400
		2008		
kaolin	i	8.0	90.3	11.3
phosphorous acid salts	f	8.7	26.9	3.10
bacillus subtilis	f	10.3	4.16	0.405
flufenacet	h	11.3	21.9	1.93
acequinocyl	i	11.3	2.89	0.255
fosetyl-AL	f	12.0	113	9.44
dimethenamid-P	h	12.0	889	74.0
fenhexamid	f	12.4	18.5	1.50
napropamide	h	12.6	24.6	1.96
pyrimethanil	f	12.7	28.1	2.22
EIQ AVE + TOTALS		11.1	1220	106
		2013/2014		
potassium salts/bicarbonate	i	8.0	231	28.9
phosphorous acid salts	f	8.7	16.1	1.86
bacillus subtilis	f	10.3	21.1	2.05
fosetyl-AL	f	12.0	494	41.1
dimethenamid-P	h	12.0	753	62.6
fenhexamid	f	12.4	126	10.2
napropamide	h	12.6	53.6	4.26
pyrimethanil	f	12.7	63.1	4.98
picoxystrobin	f	13.7	130	9.48
glyphosate*	h	15.3*	44,600	2,909
EIQ AVE + TOTALS		11.8	46,480	3,075

†does not include growth regulators or nematicides

‡f, fungicides; h, herbicides; i insecticides

*other pesticides with EIQ=15.33 includes: 2,4-D ester, cloransulam-methyl, foramsulfuron, mecoprop-p

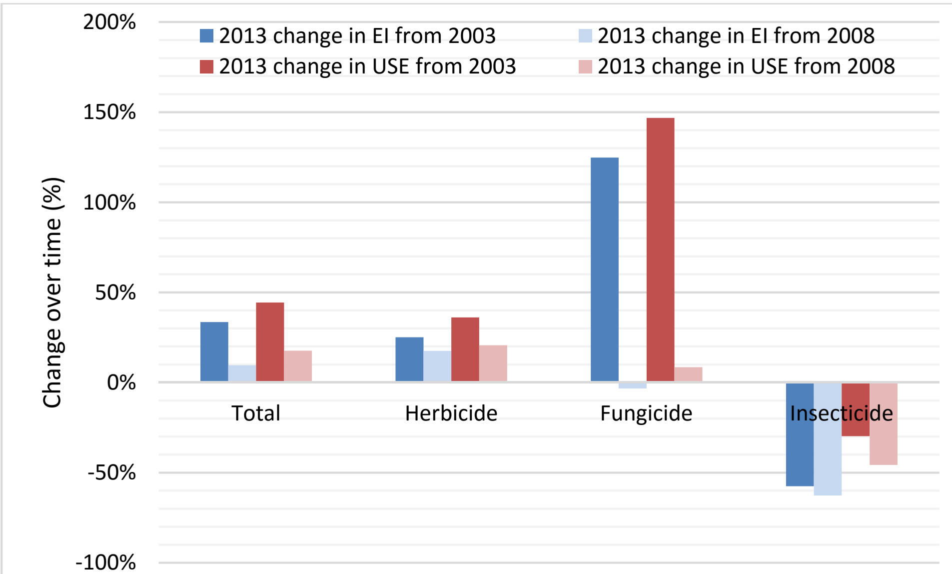

Figure 1. Change in pesticide environmental impact (EI) (blue) and use (red) in 2013/2014 relative to 2003 (darker colour) and 2008 (lighter colour). A value of 0% indicates no change over time and values above 0% indicates an increase in 2013/2014 relative to either 2003 or 2008. Total represents the sum of herbicides, fungicides and insecticides.