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GLYPHOSATE: THE WORLD'S MOST WIDELY USED HERBICIDE

Primer

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GLYPHOSATE: THE WORLD'S MOST WIDELY USED HERBICIDE

Introduction

A glycine derivative, glyphosate is a non-selective herbicide with a systemic mode of action.[1, 2] It was first described as one of the 'safest' herbicides by its manufacturer, Monsanto, when it was introduced on the market in 1974 under the trade name Roundup®.[3] Today it is used extensively worldwide, largely as a weed killer in agriculture, especially in the production of corn, soybean, cotton and pasture crops.[1, 2, 4, 5] It can also be used as a plant growth regulator[2] and can hasten the harvesting of certain grains and legumes when it is applied as an agent of dessication.[6, 7]

Its non-agricultural applications include forestry, home maintenance, and vegetation control on industrial lands and rights-of-way (e.g. train tracks, highways, etc.).[1, 2, 4, 5] Glyphosate is generally used as a post-emergent herbicide, which means it acts after seeds have germinated and plants have started to grow, and a non-selective herbicide,[8] which means that it eradicates all vegetation upon which it is applied.[2]

Glyphosate use trends

Glyphosate is the most widely used herbicide on the planet.[9] Sold in over 100 countries,[10] its global use reached 825,804 metric tonnes in 2014.[5] Because glyphosate is non-selective, its use in agriculture was initially quite limited because it could only be applied during certain times of the year to avoid crop damage. However, the introduction of genetically modified (GM) glyphosate-tolerant crops such as those in the Roundup Ready® suite, opened the door to more widespread use.[5, 11] Since glyphosate-tolerant GM crops were introduced in 1996, glyphosate use worldwide has increased by nearly 15-fold, with 56% of the total amount of glyphosate applied globally used on these crops.[5]

Glyphosate ranks number one in Canadian and Quebec herbicide sales.[12, 13] At present, 176 glyphosate-containing products are authorized in Canada.[14] Monsanto's patent on glyphosate expired in 2000, but it still manufactures the majority of these products (55 products authorized in Canada). Dow AgroSciences and Syngenta now respectively manufacture 22 and 10 products authorized in Canada.[15]

It is impossible to establish glyphosate use trends in Canada and Québec with any accuracy, because data on sales is reported by pesticide group, with few exceptions, with glyphosate being part of the group of phosphonic acids and their derivatives. Nonetheless, since the quantities of glyphosate sold in Canada far outpace those of others in the same group,[12, 16-21] it is reasonable to presume that glyphosate has a disproportionate influence on the overall sales figures for phosphonic acids and their derivatives.

Figures 1 and 2 below chart the rise in glyphosate sales in recent years. Based on the available data, sales of phosphonic acids and their derivatives in Canada increased by 47.1%, going from 28,746,017 kg of active ingredients (kg a.i.) in 2009[16] to 42,286,074 kg a.i. in 2014.[21] In Québec, though sales only increased by 19.2% during the same period (from 1,388,263 to 1,858,378 kg a.i.),[22] it must be remembered that they had increased by 689.5% — an almost eight-fold increase — between 1992 (209,687 kg a.i.[23]) and 2015 (1,655,422 kg a.i.[22]).

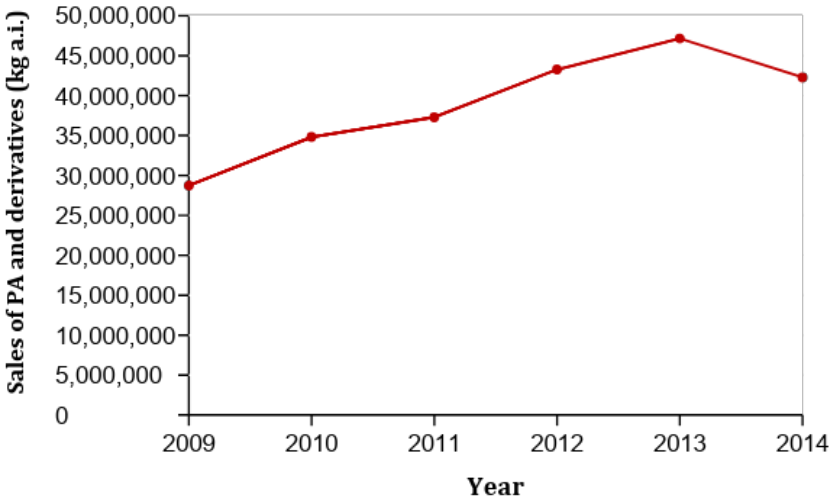

Figure 1: Annual sales of phosphonic acids (PA) and their derivatives in Canada (all sectors)[12, 16-21]

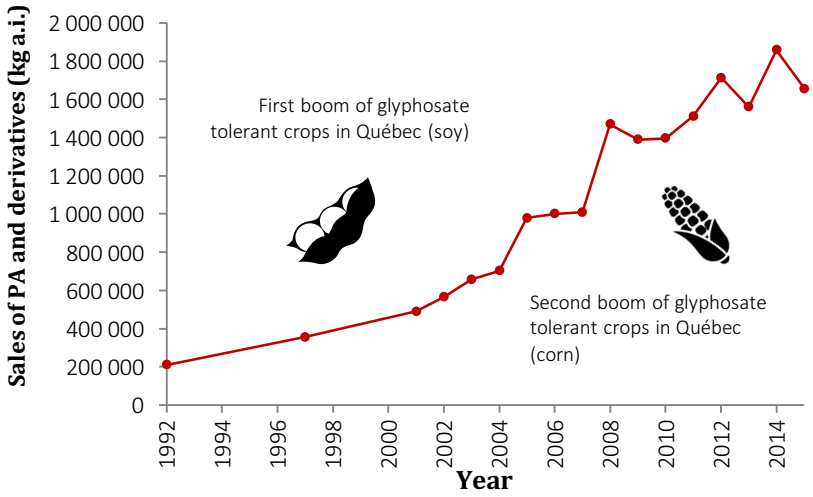

Figure 2: Annual sales of phosphonic acids (PA) and their derivatives in Québec (crop production)[22, 23]

In Québec, glyphosate-tolerant GM crops first boomed in 2002 with soy production, and then again in 2005-2006 with corn.[24] These dates would appear to correspond to the line in Figure 2. As the total number of acres of GM soy and corn have continued to dramatically increase in Quebec, so too has the annual sales of the group of pesticides called phosphonic acids and their derivatives, of which glyphosate is the major player[22, 23] (Figure 3).

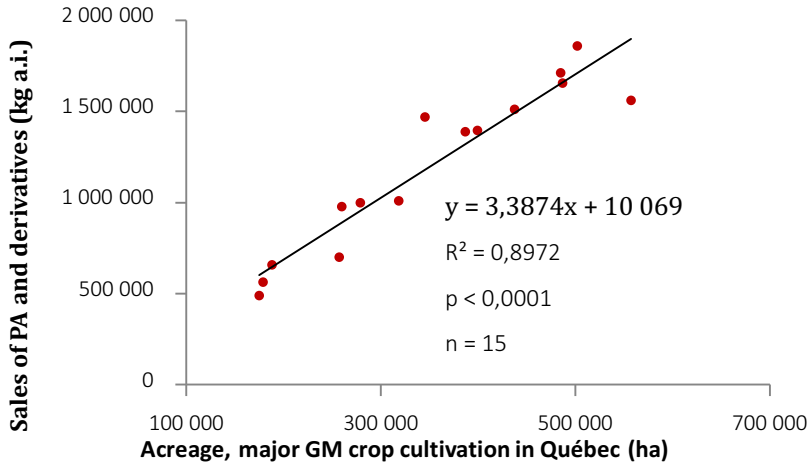

Figure 3: Correlation between GM corn/soy acreage and quantities of phosphonic acids (PA) and their derivatives sold in Québec.

Growing numbers of glyphosate-resistant weeds

Repeated use of glyphosate over years has led to the evolution of a number of resistant weed species.[25-27] Recent data suggest that between 24[26] and 32[27] weed species worldwide have now developed glyphosate resistance, with 16 of those species prevalent in fields planted with Roundup Ready crops.[26] Canadian horseweed (Erigeron canadensis) is the most widespread glyphosate-resistant species on the planet. However, Palmer's amaranth (Amaranthus palmeri) and tall water hemp (A. turberculus) present the biggest economic challenge, not just because they are widespread, but also because they have developed resistance to several herbicides.[26] Canada currently reports between four[28] and five[29] species of glyphosate-resistant weeds. The majority are found in Ontario, with one officially confirmed species in both the Canadian Prairies (ragweed [Kochia scoparia])[28, 29] and Québec (turnip rape [Brassica rapa L.]).[30]

Weed resistance is a serious problem, because it requires more frequent and/or more abundant applications, and often requires treatments that use multiple herbicides in combination.[25, 31] This not only raises the risks posed to health and the environment but also raises costs for producers. As a result, in the early 2010s, Monsanto began offering discounts to farmers who were using herbicides other than Roundup to control glyphosate-resistant plants on their glyphosate-tolerant crops.

Glyphosate contamination of natural waters

Since glyphosate isn't very mobile in soil,[2,32] it is not expected to migrate toward water, particularly groundwater.[33] In the case that glyphosate reaches surface waters, it is expected to partition to sediment despite its high solubility (between 5,800 and 12,000 mg/l.[32] This is equally true for its main metabolite, aminomethyl phosphonic acid (AMPA).[2, 32] However, leaching and runoff from soil to aquatic environments cannot be discounted because glyphosate mobility is influenced by precipitation, particularly when high rainfall events occur shortly after application.[34, 35]

Table 1 presents data collected for Monsanto between 1993 and 2011 on the extent of glyphosate and AMPA contamination in natural waters of many European nations. The data shows that this contamination occurs with extremely high frequency (up to 92.5% for glyphosate and 100% for AMPA) or at high concentrations (up to 370 µg/L of glyphosate and above 200 µg/L of AMPA).[36] The contamination in groundwater is less severe, with glyphosate and AMPA being detected less frequently (3.4% and 12%, respectively) and at lower concentrations (24 µg/L and 19 µg/L, respectively).[36]

Table 1: Presence of glyphosate and AMPA in the natural waters of European countries[36]

Country	Glyphosate[a]			AMPA[a]		
	n	Detection freq. (%)	Max. Conc. (µg/L)	n	Detection freq. (%)	Max. Conc. (µg/L)
Surface waters						
Austria	ND	ND	ND	345	≥26	3.4
Belgium	5,881	≥ 83	139	5,351	92.8	3,4
Czech Republic	359	47.8	5.3	165	100	1.37
Finland	26	11.5	0.46	26	11.5	0.22
France	57,171	30.2	50	46,969	51.8	48.9
Germany	1,298	29.7	4.7	782	57.5	3.6
Ireland	2,483	5.6	186	496	0.2	> 200
Italy	919	24,3	37,6	239	87,0	37
Norway	80	92.5	0.93	80	92.5	0.54
Slovenia	2,092	15.3	3.6	ND	ND	ND
Spain	115	7.4	15.3	ND	ND	ND
Sweden	1,306	27.6	370	1,285	19.0	4.0
Suède	1 306	27,6	370	1 285	19,0	4,0
UK	3,730	20.3	8.2	ND	ND	ND
Groundwater						
Austria	3,633	0.19	> 0,1	3,636	1.2	0.75
Belgium	> 2,338	< 0.02	< 0.025	> 4,383	< 0.41	1.85
Denmark	9,908	1.2	4.7	9,906	0.84	4.2

Finland	80	0	BDL	80	0	BDL
France	45,960	1.1	24	30,529	1.4	19
Germany	≥196	ND	≤0.1	≥326	ND	≥1
Ireland	679	0.8	0.19	ND	ND	ND
Italy	961	0	BDL	≥ 619	≤ 0.5	0.9
Malta	≥ 18	0	BDL	ND	ND	ND
Netherlands	691	0.58	4.7	691	3.0	5.1
Norway	8	0	BDL	8	12.5	0.02
Sweden	1,247	0.08	0.08	1,242	0.24	0.72
Switzerland	≥234	3.4	0.21	≥ 232	ND	0.46
UK	1,509	0.9	0.47	ND	ND	ND

a: ND = non-determined; BDL = below detection limit

Table 2 indicates a different picture in North America. While glyphosate and AMPA are generally found at higher concentrations in surface waters (up to 427 µg/L and 397 µg/L respectively) than in groundwater (up to 45 µg/L and 4,88 µg/L), their detection frequency in North American groundwater is much higher (up to 100%). Glyphosate and AMPA are generally detected very frequently in precipitation,[37-41] largely due to aerial drift and wind erosion.[41, 42]

Table 2: Presence of glyphosate and AMPA in natural waters, North America[a]

Country	Glyphosate[b]			AMPA[b]			Ref.
	n	Detect. Freq. (%)	Max. Conc. (µg/L)	n	Detect. Freq. (%)	Max. Conc. (µg/L)	
Surface waters							
Canada (AB)	110	25.45	6.1	110	6.36	4	43
Canada (CB)	ND	ND	9,000	ND	ND	ND	44
Canada (ON)	529	32	5.38	ND	ND	ND	45
Canada (ON)	74	56.8	3,380	219	74	48.6	46
Canada (ON)	502	17	40,800	502	5.6	66,000	47
Canada (ON)	210	33	12.0	ND	ND	ND	45
Canada (ON)	96	82.3	41,881	96	88.5	14,781	46
Canada (QC)	31	65	0.400	31	94	0.860	48
Canada (QC)	ND	91.1	18	ND	67.0	2.9	49
U.S. (10 States)	40	17.5	2.2	40	67.5	3.9	50
U.S. (39 States)	2 304	54,7	427	2 304	73,6	397	37
U.S. (NAWQA)	608	32.2	9.7	608	51.5	8.7	37
Mexico (wet season)	ND	ND	1,33	ND	ND	ND	51
Mexico (dry season)	ND	ND	36.71	ND	ND	ND	51
Groundwater							
Canada	72	32	0.02	ND	ND	ND	52
Canada (AB, ON)	281	13.2	0.042	281	11.7	2,870	53

Canada (NL)	ND	ND	45	ND	ND	ND	54
Canada (ON)	401	10.5	0.663	401	5.0	0.698	39
U.S. (39 States)	1,171	5.8	2.03	1,171	14.3	4.88	37
U.S. (NAWQA)	485	5.8	0.67	485	9.5	0.62	46
Mexico	20	100	1.41	ND	ND	ND	55
Mexico	6	100	0.38	ND	ND	ND	55
Mexico (wet season)	ND	ND	0.56	ND	ND	ND	51
Mexico (dry season)	ND	ND	18.43	ND	ND	ND	51
Precipitation							
Canada (ON)	15	86.7	0.135	15	26.7	6.7	39
U.S. (39 States)	85	70.6	2.5	85	71.8	0.48	37
U.S. (IA, IN, MS)	80	71.2	2.5	80	62.5	0.48	40
U.S. (IN)	14	85.7	1.1	14	85.7	< 0.2	46
U.S. (MS)	ND	77	1.90	ND	77	0.270	41

a: Some results were recalculated based on individual data in the studies consulted, in particular to better discriminate between environments (forest, rural and urban)

b: ND = non-determined; BDL = below detection limit

In Canada, glyphosate contamination measured in surface and groundwater (Table 2) remain consistently below the Canadian Water Quality Guideline (CWQG) that has been set to protect aquatic life (800 µg/L for chronic exposure).[56]

Glyphosate and AMPA are very frequently detected in surface waters in Québec (Table 2). Between 2011 and 2014, both were respectively found in 91.1% and 67.0% of samples from agricultural rivers, with the maximum respective concentrations measured at 18 µg/L and 2.9 µg/L.[49] A previous study conducted between 2003 and 2008 reported an even higher detection frequency (94%) for AMPA.[48] Glyphosate contamination also continues to increase in recent years in rivers near farms in Quebec. Between 2002 and 2014, median concentrations rose from 0.01977 µg/L to 0.04625 µg/L per year in four rivers in corn- and soybean-growing areas (Figure 4).[49] Nonetheless, in both studies,[48,49] the levels detected remained below the chronic aquatic life toxicity criterion (CVAC) for glyphosate in Québec, set at 65 µg/L.[57]

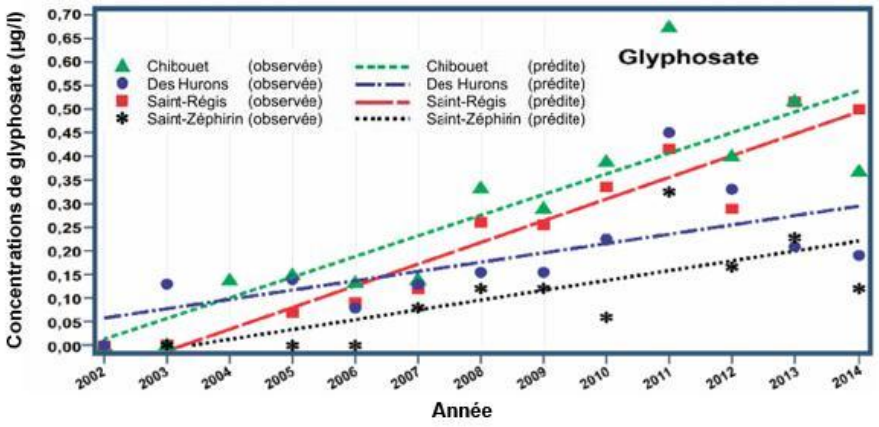

Figure 4: Linear regression applied to median concentrations of glyphosate measured in four Québec rivers between 2002 and 2014[49].

The Minister of Sustainable Development, the Environment and Climate Change in Québec(MDDELCC) determined the relative annual contribution of all pesticides to the overall environmental risk posed by all pesticides used in Québec, by considering the ecotoxicological and physiochemical properties of each pesticide as well as the quantities used (for details and calculations, see Samuel et al, 2012[56]). Glyphosate's contribution to overall environmental risk has varied little between 2008 and 2015 (Table 3), contributing between 2.9%[59] and 4.0%.[60,61] Despite a 12.7% increase in phosphoric acid and derivatives sales over the same period, its contribution to the environmental risk has gone from fourth [59] to eighth place.[62]

Table 3: Contribution of glyphosate to the environmental risk in Québec between 2008 and 2015.

Year	Contribution (%)	Rank	Reference
2008	2.9	4	59
2009	3.9	4	23
2010	4.0	6	60
2011	3.7	6	63
2012	4.0	6	61
2014	3.5	7	64
2015	3.0	8	62

Drinking water contamination by glyphosate

Surface and groundwater are the primary sources of drinking water for the world's population,[65] including in Canada66 and Québec[67, 68] and glyphosate contamination therefore impacts the water we drink. Given its known or suspected toxic effects on humans (addressed in greater detail in the following section), several countries have issued guidelines regarding the maximum limit of glyphosate contamination acceptable in drinking water. Figure 5 shows that these guidelines vary dramatically

from one place to another. The World Health Organization (WHO) has not set guidelines for acceptable limits to glyphosate contamination because it deems that drinking water concentrations are "well below those of health concern."[69]

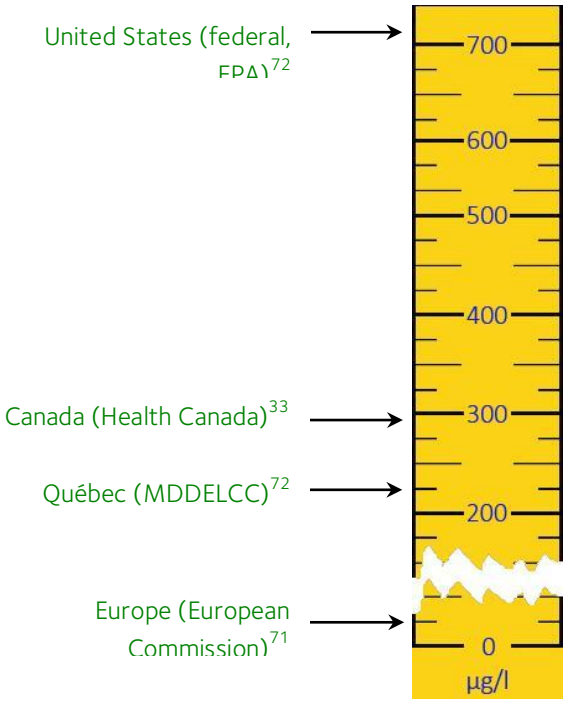

Figure 5: Recommended maximum concentrations of glyphosate in drinking water issued by different public bodies.

In Québec, drinking water quality assessments conducted between 2005 and 2014 detected glyphosate only in 2006, 2010 and 2013, at respective maximum concentrations of 2.1, 0.7 and 1.5 µg/L,[73, 74] levels that fall below provincial drinking water recommendations (< 210 µg/L).[70] In addition, data on drinking water quality from Montréal's two main treatment plants, Atwater and Charles-J.-Des-Baillets, indicate that glyphosate concentrations have consistently remained below the detection level between 2009 and 2016.[75-82]

Toxic effects of glyphosate on living organisms

Glyphosate acts on the biosynthesis of shikimic acid, a metabolic pathway present in plants and certain microorganisms but not in animals.[83] For this reason, it is seen as relatively safe in higher-order species, with acute toxicity ranging from low (500 mg/kg < dL50 ≤ 5,000 mg/kg) to very low (dL50 > 5,000 mg/kg), depending on the route of exposure and organism involved.[1] However, additives in commercial formulations containing glyphosate — for example, the surfactants that let it penetrate plant cuticles[8, 84] — can themselves be toxic[85] and thus serve to raise the overall toxicity of the glyphosate-based products.[86, 87]

In humans, the effects of acute non-lethal toxicity include irritation of the gastrointestinal tract, liver and kidney disorders, respiratory distress, pulmonary edema and arrhythmia.[88] While high doses are required to produce a lethal effect in many aquatic and terrestrial vertebrates, certain fish and aquatic invertebrates are more sensitive.[89] Among mammals (cats and dogs), acute toxicity gives rise to such symptoms as anorexia, lethargy, hypersalivation, vomiting and diarrhea, though few cases of acute toxicity result in mortality.[1] However, studies have also shown glyphosate to be toxic to amphibians and phytoplankton at concentrations below current surface water standards.[89, 90]

Ironically, glyphosate may compromise certain ecosystem services and even negatively impact agricultural productivity by harming terrestrial invertebrates and microorganisms. For instance, monarchs are an important pollinator species, but there is a link between extensive glyphosate-use and the decline in monarch butterfly populations, because glyphosate is designed to kill milkweed which is the monarch caterpillar's main food source.[91] Bees are also important pollinators, and glyphosate affects their navigational capacity, which can lead to death by starvation.[92] Finally, glyphosate is known to impact key interactions between earthworms and mycorrhiza,[93] which are two organisms vital to plant nutrition and agricultural productivity.

While there is general consensus in the literature about the effects of acute exposure to glyphosate, opinions are divided as to the toxicity of chronic exposure. Numerous studies report adverse effects on organs and functions in several vertebrate classes (some of which are listed in Table 4). However, these studies are contested by a number of others citing a methodological bias or insufficient data in the scientific evidence base to conclusively establish the toxic effects of glyphosate and its end-use products on humans and animals.[10, 94-98]

Table 3: Synthesis of the toxic effects of glyphosate (G) or its formulated products (CP) in different vertebrate classes. The figures in the cells refer to studies reporting these effects (underscored = effects attributable to G; bold = effects attributable to CP; underscored + bold = effects attributable to G and CP; italics = study does not specify whether the effects are attributable to either). The symbol "×" doesn't indicate a lack of effects but rather that no article had been found.

Organisms / Effects	Humans	Mammals	Birds	Reptiles	Amphibians	Fish
Cancers and tumours	*100*,102, 103	*113*	×	×	×	×
Cytotoxicity	**99**, **104**	112	×	×	124	×
Endocrine disruption	99, 108, 107, **108**	111, 112, 119	118	×	123	×
Genotoxicity	105, 106	105, 110	×	121	123, 124, 125	129, 130, 131

Hepatic changes	99, *100*	110	×	×	×	126, 127
Immunotoxicity	×	*31*	×	122	×	127
Intestinal microbiota disruption	*100*	115	119	×	×	×
Neurotoxicity	106	114	×	×	×	131
Renal changes	*100*	110	×	×	×	126, 127
Reproductive changes	101	111, 112	118	×	123	128
Teratogenicity	109	111, 117	120	121	120, 123	132

There are various possible explanations for the uncertainties around the chronic toxicity of glyphosate. First, there's the fundamental difference between two concepts often used interchangeably: hazard and risk. "Hazard" refers to the harm something may cause, while "risk" refers to the likelihood that a hazardous material will cause harm. Risk is modulated by two factors: the degree of hazard posed by the substance and the level of exposure to it.[133] A hazardous substance will carry a high risk of toxicity given a substantial degree of exposure; conversely, the same substance will carry only a slight risk if exposure remains low.

The majority of studies reporting toxic effects used glyphosate dosages exceeding the typical level of exposure for either workers who handle the herbicide[134] or the general population for whom contact comes through food[135] or drinking water.[69] While the studies highlight glyphosate's danger, these studies shed little light on the actual risk associated with it. In particular, the risk to human health is said to be low, based on chronic toxicity studies using laboratory animals; however, a lack of information on glyphosate toxicity at low-dose exposure does not imply a corresponding lack of effect. That is, absence of evidence is not evidence of absence. Glyphosate's reputation is therefore not based on scientific consensus, since the studies needed to properly assess the risks have not been carried out.

There are several gaps and uncertainties in the scientific literature. Lifelong studies have not yet been carried out on laboratory animals, nor have any large-scale epidemiological studies correlated glyphosate levels in urine to the state of health of the population studied. While the risks associated with glyphosate continue to be a matter of dispute, in 2015 a group of researchers published a consensus statement advocating that the uncertainties be taken into account in the regulation by imposing a ten-fold safety factor onto the acceptable daily intake.[136]

Furthermore, some studies have focused on formulated products while others considered only the active ingredient. As indicated above, certain additives (particularly POEA) raise the toxicity of formulated glyphosate-based products.[85-87] Nonetheless, the findings on end-use product toxicity of

many health authorities around the world are based largely on studies that consider the active ingredient in isolation.[107, 137] Therefore, these authorities do not recognize certain toxic effects.

Also, many have decried the dataset used by health authorities as being outdated and point to the large proportion of grey literature used in toxicological evaluations.[107, 137, 138] For example, during the EPA's 1993 registration review of glyphosate,[2] 73% of nearly 300 citations were published prior to 1985 (eight or more years), and just 11 (i.e. less than 4%) were peer-reviewed.[137,139] Furthermore, a review of the PMRA's 2017 glyphosate re-evaluation decision revealed that, despite there being no shortage of recent studies, the agency had assessed glyphosate's toxicological dangers on the basis of 118 industry documents that had not been peer-reviewed or published in academic journals, 80.5% of which pre-dated 1996 (11 or more years).[138]

Finally, assessments of glyphosate's risk are often tainted by conflicts of interest, as exemplified by the heated debate over glyphosate's carcinogenicity. In 2015, the International Agency for Research on Cancer (IARC) ranked glyphosate as a probable carcinogen for humans (group 2A classification). [140] However, the Joint FAO/WHO Meeting on Pesticide Residues (JMPR)[141] came to a very different conclusion: glyphosate is unlikely to be a human carcinogen. Other regulatory bodies, including the European Food Safety Authority (ESFA), [139] the EPA, [142] the European Chemicals Agency (ECHA)[143] and the PMRA,[144] agreed with the JMPR.

The difference in opinion may well be rooted in methodological approaches between the IARC and the JMPR[145, 146], but both organizations' risk assessment conclusions have been accused of being influenced by conflicts of interests. If, on the one hand, the IARC was said to have had a partisan evaluation committee,[145, 147] the JMPR in turn was said to have been influenced by industry stakeholders.

Internal documents[148] unsealed in a lawsuit brought against Monsanto by a number of plaintiffs with non-Hodgkin's lymphoma indicate that the company employed fallacious tactics to restore the image of its flagship product.[149, 150] These tactics included Monsanto having a number of illustrious researchers sign a paper that, in reality, had been ghost-written by its staff[149-153]. The paper[154] was published in 2016 as one of a five-article series[155-158] in a special supplement of the scientific journal Critical Reviews in Toxicology.[155] Some claim that the articles influenced ongoing risk assessments in multiple jurisdictions that were underway.[154]

Obtaining a balanced picture of the toxicological risks of glyphosate is of vital importance because it is so widely used. Indeed, as shown by the data compiled for Québec, while glyphosate's contribution to

health risks[58] appears low, the percentage has generally been trending upwards in recent years (Table 4).

Table 4: Contribution of glyphosate to health risks in Québec between 2008 and 2015.

Year	Contribution (%)	Rank	Reference
2008	3.2	6	59
2009	4.6	6	23
2010	6.3	5	60
2011	6.1	5	63
2012	7.1	4	63
2014	7.0	4	64
2015	6.4	4	62

Glyphosate registration and re-evaluation in Canada

Glyphosate-based products have been authorized in Canada since 1976.[144] In 2010, Health Canada published a re-evaluation work plan for glyphosate-based products, which by law requires the PMRA to re-evaluate all of the environmental and health risks of glyphosate and determine if they are not unacceptable.[159]

In 2015, the PMRA published its proposed re-evaluation decision for public consultation[32] and in 2017, issued its ruling: "[T]he PMRA is granting continued registration of products containing glyphosate with requirements of additional label updates to further protect human health and the environment."[144] These label requirements are not extensive.[144]

The PMRA's evaluation process and final decision stimulated critique. In accordance with article 35 (1) of the Pest Control Products Act (PCPA), at least four notices of objection were sent to Health Canada.[138, 160-162] Prepared by two researchers at Université du Québec à Montréal (UQAM), one of the notices objected to the following: i) the incompleteness of the PMRA's literature review; ii) the antiquity of the majority of the studies consulted; iii) the lack of rationale presented to justify omission of the numerous more recent studies; iv) the failure to take into consideration the sharp increase to glyphosate sales in the risk assessment; and v) the failure to systematically consider the additives present in formulated products, despite the fact that these are considered more toxic than glyphosate.[138]

Another notice of objection was prepared by a coalition of environmental groups (Équiterre, David Suzuki Foundation, Canadian Association of Physicians for the Environment (CAPE), Environmental Defence and Prevent Cancer Now), and pointed to the PMRA's failure to consider all risks posed by

glyphosate, including i) glyphosate's impact on milkweed and the decline in monarch butterfly populations; ii) glyphosate's impact on soil and human intestinal microbiota; iii) its role in the emergence of various diseases, including cancer; iv) its capacity for bonding to metal, thus contributing to soil depletion and the mobility of cadmium — a carcinogenic, neurotoxic heavy metal — in grains; and v) the failure of riparian strips or buffer zones to protect the environment.[160]

Both notices of objection stated that the PMRA's required labelling modifications fell far short of being able to ensure adequate protection of human health and the environment.[138, 160, 161] Because the re-evaluation was flawed, Health Canada cannot determine conclusively that glyphosate does not present an unacceptable risk to humans and the environment, which is the first requirement of the Pest Control Products Act (PCPA). The groups call on the Federal Minister of Health to review the decision with an independent expert panel.[160]

After glyphosate was classified as a potential human carcinogen by the IARC, around 4000 lawsuits were filed against Monsanto by people alleging that exposure to the glyphosate-based herbicide Roundup caused them to develop non-Hodgkin lymphoma, and that Monsanto deliberately covered up the risks. The 46 year old American gardener Dewayne Johnson suffering from an intractable non-Hodgkin lymphoma[163], causing him skin lesions throughout his body, took the very first legal action against Monsanto. In August 2018, the Californian Supreme Court rendered a landmark decision sentencing Monsanto to pay 290 million dollars to Johnson[164] to repair the damages caused by its glyphosate-based herbicides. The judge also allowed many of Monsanto's internal documents and communications to be made public, revealing the negotiations between the EPA and Monsanto to downplay the cancer risk assessment and discourage any further evaluation of the toxicological risks of glyphosate[165].

In 2017, California put Glyphosate on the list of potential carcinogen products[166]. From now on, every manufacturer aware of the potential carcinogen nature of its product will have to mention it on labels.

Conclusion

Glyphosate is the most widely used herbicide in the world,[9] in large part as a result of the rise in glyphosate-tolerant GM crops over the past two decades.[5, 11] Glyphosate use continues to increase in Canada[12, 16-20] and Québec[22, 23].

The widespread use of glyphosate has led to the development of resistance in numerous weed species,[25-29] which reduces the herbicide's effectiveness and increases both weed management costs[31] and risks. The extensive use of glyphosate also contaminates surface waters [36-37, 43-51] and to a lesser degree, groundwater.[36, 37, 39, 46, 51-55] However, the measured concentrations of glyphosate and its main metabolite AMPA remain relatively low; the studies consulted for Canada[39, 43-47, 52-54] and Québec[48, 49] show that contamination does not exceed the guidelines established for the protection of aquatic life. However, concentrations measured in certain water bodies (in Québec for example[49]) have been found to be on the rise in recent years. Many studies consider that glyphosate has negative impacts on ecosystems and agriculture; for example, it contributes to the destruction of milkweed, the primary food source for monarch butterfly caterpillars (an insect whose population has been in freefall since the early 2000s[91]), plays a role in the ongoing decline of honeybee populations[92] and affects interactions between earthworms and mycorrhiza.[93]

A further concern is the presence of glyphosate in surface waters and groundwater, which often serve as drinking water sources.[65-68] Again, while the reported concentrations[72-82] remain below the guidelines set in many countries,[33, 69-72] studies that predate the introduction of GM crops may underestimate current concentrations.[72] Furthermore, the significant differences in the drinking water guidelines issued by different countries create uncertainty about what an acceptable level is. For instance, while the U.S. recommendation of 700 µg/L[72] is 7,000 times less restrictive than the standards applied in the EU (0.1 µg/L[71]), its value is nonetheless close to that of the RCQE regarding the protection of aquatic life (800 µg/L).[56] Data also indicate that glyphosate's contribution to health risks has been on the rise in recent years in Québec.[23, 56-61]

Concerns about glyphosate's presence in drinking water (as well as its residues in foods[135]) are concerning because of the potential toxicological effects described in numerous studies.[88, 99-109]. However, recognition of these effects is not unanimous, particularly due to methodological factors (e.g. the distinctions between "hazard" and "risk,"[133] the consideration or not of additives in formulated products containing glyphosate,[137] and the obsolescence of scientific literature used for toxicological evaluation[137, 138]), but also due to conflicts of interest[145, 147] and the use of unethical tactics by pesticide manufacturers.[148-153]

These debates, which have entered popular media, negatively impact the scientific committees, national and supranational regulatory bodies tasked with certifying and regulating the use of glyphosate. The controversy around the question of glyphosate's carcinogenicity aptly illustrates this phenomenon.[145] Like a number of national and supranational authorities[139, 142-144], the PMRA recently decided to grant continued registration to glyphosate. The decision drew extensive criticism from civil society stakeholders, who called upon the agency to conduct a more rigorous, transparent and impartial evaluation.[138, 160-162] The PMRA failed to consider all risks posed by glyphosate. It didn't consider glyphosate's impact on milkweed and the decline observed in monarch butterfly populations; its impact on soil and human gut microbiota; its role in the emergence of various diseases, including cancer; its capacity for bonding to metal, thus contributing to soil depletion and the mobility of cadmium — a carcinogenic, neurotoxic heavy metal — in grains; and the failure of riparian strips or buffer zones to protect the environment.[160] PMRA's required labelling modifications fell far short of being able to ensure adequate protection of human health and the environment.

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