



CENTER FOR
FOOD SAFETY

Supplemental Materials *for*

MONARCHS IN PERIL: Herbicide-Resistant Crops and the Decline of Monarch Butterflies in North America

In these supplemental materials, we discuss the data sources and methodologies that were used to arrive at the estimates of glyphosate use portrayed in various graphs included in the report.

Why Center for Food Safety Relied on USDA NASS Data

The reported figures on glyphosate use on corn and soybeans are based on Agricultural Chemical Usage surveys conducted by USDA's National Agricultural Statistics Service (NASS). NASS has collected and published agricultural chemical use data since 1990, and made them freely available to the public (for data used in this report, see USDA NASS 2013, 2011, 1996-2007). NASS data are based on surveys of thousands of farmers, and are regarded as the most accurate information on national pesticide use in American agriculture. The NASS program ensures "a high level of data reliability and accuracy, which are the greatest advantage of NASS data. NASS employs rigorous methods to ensure that statistically representative samples [of farmers] are achieved" (NASS Advisory 2006).

Pesticide use data are also available, at high cost and by subscription only, from private firms such as Doane. However, the survey methodologies employed by such private firms are proprietary, and hence the pesticide use data they generate (also proprietary) may in some cases be unreliable due to use of statistically unrepresentative sampling techniques.

The proprietary agreements entered into by Doane subscribers extend well beyond prohibitions on data disclosure, to embargo revelation of the sampling and analytical procedures used to generate their data. Thus, it may be that a large number of the area wide estimates included in the Doane system are based on individual or statistically unrepresentative observations (NASS Advisory 2006).

Methodologies for Use of NASS Glyphosate Data

NASS collected pesticide use data for corn and soybeans in over half of the years from 1995 to 2013. Surveys were conducted almost every year through 2005, and less frequently thereafter due to budget shortfalls. NASS surveys focus on those states (the "Program States") where most of the crop is grown. For the 1995-2013 period, NASS surveys covered on average of 88% of the nation's soybean and likewise 88% of the nation's corn crop (Table 1).

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Table 1: Percent National Crop Acres Surveyed by NASS for Pesticide Use

	Soy	Corn
1995	83%	90%
1996	79%	88%
1997	n.s.	n.s.
1998	91%	89%
1999	92%	88%
2000	97%	93%
2001	71%	93%
2002	97%	65%
2003	n.s.	92%
2004	81%	n.s.
2005	89%	93%
2006	96%	n.s.
2007	n.s.	n.s.
2008	n.s.	n.s.
2009	n.s.	n.s.
2010	n.s.	93%
2011	n.s.	n.s.
2012	96%	n.s.
2013	n.s.	n.s.
Average 1995-2013	88%	88%

Source: USDA-NASS (2013, 2011, 1996-2007).
n.s. = no survey for this year.

NASS reports pesticide use, by crop, for each Program State and for the Program States as a whole. CFS has reproduced NASS soybean herbicide use data for all Program States combined for 2005 at the end of these supplementary materials to illustrate how these data were used to construct the various graphs in this report.

NASS reports the following data on each pesticide whose use is great enough to allow for reliable estimates:

- 1) Area applied (expressed as % of planted acreage);
- 2) Average number of applications per year;
- 3) Average rate per application;
- 4) Average rate per year (the product of 2 and 3 above); and
- 5) Total applied.

Figure 7: Glyphosate Use on Corn and Soybeans in the U.S.: 1995-2013

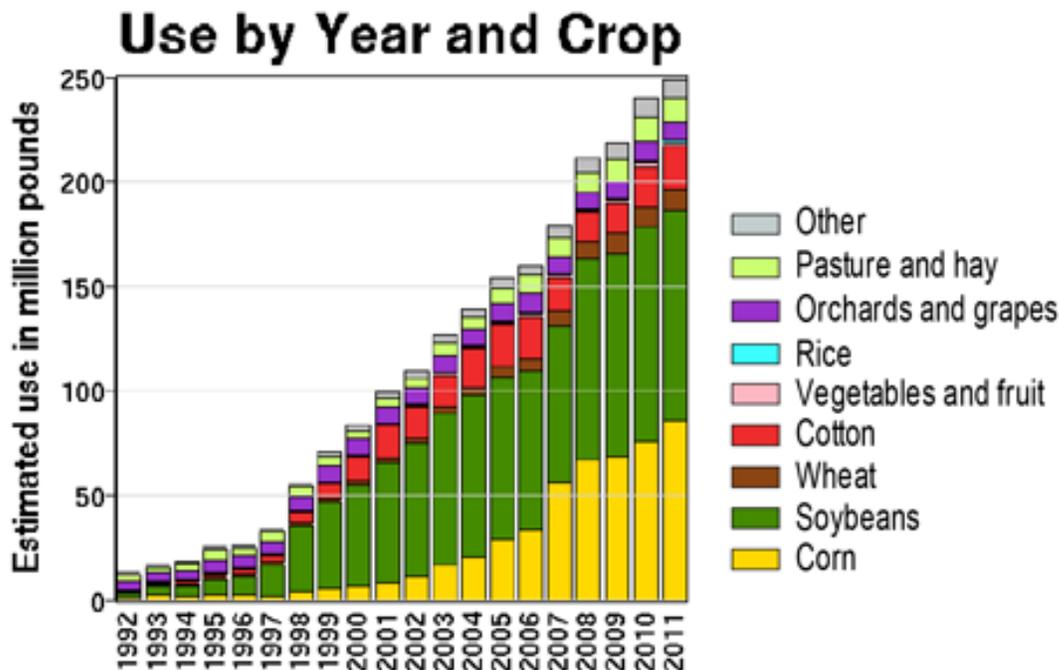
This figure shows total national use of glyphosate on corn and soybeans from 1995 to 2013. Three steps are required to arrive at the figures in this graph. First, one must add the total applied for each form of glyphosate used on the given crop (corn or soybeans) in the Program States for the given year. Second, one must normalize this total to estimate national usage, and to provide figures that are comparable from year to year given variations in the percentage of acres surveyed, as shown in Table 1. Third, the normalized totals for corn and soybeans are added to give total national use of glyphosate on corn and soybeans. We describe these steps with reference to the 2005 soybean data reproduced below.

Three forms of glyphosate were used on soybeans in 2005: glyphosate (1.683 million lbs.), glyphosate iso. salt (63.047 million lbs.) and sulfosate¹ (2.681 million lbs.), for a total of 67.411 million lbs. This represents the total amount of glyphosate applied to soybeans in the Program States in 2005. The Program States in that year represented 89% of national soybean acreage (Table 1 above; USDA NASS 2006, p 4). Glyphosate was of course also

¹ Glyphosate iso. salt refers to the isopropylamine salt of glyphosate; sulfosate is the trimethylsulfonium salt of glyphosate. See <http://www.weeds.iastate.edu/mgmt/qtr00-1/touchdown2.htm>. “Glyphosate” refers to other forms of glyphosate. See also USDA NASS (2006), pp. 147, 150.

used in other, unsurveyed, states, and there is no reason to expect that the amount used differed from that used on soybeans in Program States. The best estimate of national use would then be Program State usage divided by percent acres surveyed, in this case 67.411 million divided by 0.89 = 75.743 million lbs. Carrying out the same steps on the 2005 corn data yields a national total of 26.304 million lbs., for combined national glyphosate use on corn and soybeans of 102.047 million lbs., the figure portrayed for 2005 in Figure 7.

Glyphosate use for years in which NASS did not conduct surveys (Table 1) was linearly interpolated (e.g. 2006 to 2009 for corn) or extrapolated (e.g. 2013 for soybeans). Interpolation and extrapolation are justified in cases where a clear trend is evident, and there is no doubt that glyphosate use on corn and soybeans has steadily risen due mainly to increasing adoption of glyphosate-resistant, Roundup Ready varieties over the 1995-2013 time period. The accuracy of these interpolated/extrapolated values is also corroborated by the close convergence of our data with those from the US Geological Survey (USGS), which also provides pesticide use data from a different source (see bar graph below).



Source: Estimated Agricultural Use of Glyphosate: Epest-Low. US Geological Survey (USGS). Compare yellow and green bars for corn and soybean shown here to Figure 7 of the report. USGS obtains data from GfK Kynetec, Inc. (Thelin and Stone 2012). http://water.usgs.gov/nawqa/pnsp/usage/maps/show_map.php?year=2005&map=GLYPHOSATE&hilo=L, last visited July 29, 2014.

Figure 8: U.S. Corn and Soybean Acres Treated With Glyphosate: 1995-2013

This figure shows combined U.S. corn and soybean acres treated with glyphosate from 1995 to 2013. Four steps are required to arrive at the figures shown in the graph. First, the “area applied” percentages for each form of glyphosate are added together for total percentage of Program State acres treated with glyphosate in the given year. Second, this total percentage is multiplied by the national acres planted to the pertinent crop in the given year as reported by NASS. Third, the acres of corn and soybeans treated with glyphosate are summed to give total glyphosate-treated corn+soybean acres, represented by the bars in Figure 8. Total glyphosate-treated acres of corn and soybean are then divided by total planted acres of the two crops to give the “percent acres treated” line in Figure 8. We describe these steps with reference to the 2005 soybean data reproduced below.

The three forms of glyphosate were applied to 3% (glyphosate), 88% (glyphosate iso. salt) and 2% (sulfosate) of Program State soybean acres, for a total of 93%. 0.93 times 72.032 million acres (total planted acreage of soybeans) yields 66.99 million acres treated with glyphosate. The 2005 corn data show that 34% of 81.779 million planted acres were treated with glyphosate, giving 27.805 million acres, or 94.795 million combined corn and soybean acres treated with glyphosate, the figure represented by the bar in Figure 8. Dividing that figure by 153.811 million total corn+soybean acres yields 62% of acres treated with glyphosate, as represented by the line in Figure 8. The only assumption made here is that the percent acres treated by glyphosate in non-Program States is equivalent to that treated in the Program States.

Figure 10: Intensity of Glyphosate Use on U.S. Corn and Soybeans; 1995-2013

In this figure, we simply plot the “rate per crop year” figures (lbs./acre/year) for glyphosate for corn and for soybeans in each year. The only complication arises when different forms of glyphosate are used at different rates. For years in which multiple forms of glyphosate were used, we simply took the weighted average of the pertinent “rate per crop year” figures as shown in the formula below with reference to the 2005 soybean data reproduced above.

$$\begin{array}{c} \text{Glyphosate} \quad \text{Glyph iso.} \quad \text{Sulfosate} \\ \text{Average glyphosate use rate} = \frac{3 \times 1.020}{3+88+2} + \frac{88 \times 1.101}{3+88+2} + \frac{2 \times 1.752}{3+88+2} = 1.112 \end{array}$$

The weighted average use rate for the three forms of glyphosate is 1.112 lbs./acre/year, as one would expect very near that for the predominant form used (glyphosate iso. salt).

Figure 11: Estimated U.S. Corn and Soybean Acres Receiving Two Glyphosate Applications Per Year: 1995-2013

As explained in the text, this graph portrays a simulation based on the assumption that all corn and soybean farmers use glyphosate once or twice, but not three times or more per season. The key figure is average number of applications per season. It is most easily understood intuitively with reference to a simple mathematical example. If 1,000 acres are treated on average 1.5 times per year, then half of the acres are treated once and the other half treated twice with glyphosate.

$$\frac{(500 \text{ acres} \times 1 \text{ app/year}) + (500 \text{ acres} \times 2 \text{ apps/year})}{1,000 \text{ treated acres}} = \frac{1,500}{1,000} = 1.5 \text{ apps/year.}$$

Similar calculations show that, for instance, an average application frequency of 1.2 means that 800 acres are treated once and 200 acres treated twice $(800 \times 1) + (200 \times 2) = 1,200$, which divided by 1,000 = 1.2, and so on. Generally, if x = twice-treated acres, T = total treated acres and App = average number of applications, then:

$$x = (\text{App} - 1) \times T$$

As with glyphosate use intensity, one must take the weighted average of the number of annual glyphosate applications for different forms of glyphosate.

The 2005 soybean data shows that 3% of soybeans are treated 1.2 times/year (glyphosate), while both the iso. salt form (88%) and sulfosate (2%) are used 1.5 times per year. The weighted average is 1.49 applications per year. In 2005, 66.99 million acres were treated with glyphosate. Therefore:

$$x = (1.49 - 1) \times 66.99 \text{ million} = 0.49 \times 66.99 \text{ million} = 32.8 \text{ million acres.}$$

The same operations on corn yield 8.0 million twice-treated acres, for 40.8 twice-treated corn+soybean acres, which represents 27% of total corn+soybean acreage in that year, as shown in Figure 11.

Figure 12: Estimated Area Planted to Roundup Ready Corn and/or Soybeans in Successive Years: 1997 to 2013

This simulation utilizes USDA data on crop rotations (see citations in report) and herbicide-resistant crop adoption rates (see Figure 6) to estimate the corn and soybean acreage that is planted to a Roundup Ready variety (either corn or soybeans) in successive years. The table below summarizes the calculations for the 2005 crop year.

Table 2: Estimated Area Planted to Roundup Ready (RR) Corn and/or Soybeans in Successive Years							
Y1 Crop	Y2 Crop	Rotation Factor Y1 to Y2 Crop (%)	RR Adoption Factor Y1 Crop 2005 (%)	RR Adoption Factor Y2 Crop 2005 (%)	RR Rotation Factor (%)	Y1 Crop Acres 2005 (mill.)	Acres (mill.) in RR Crops Y1 and Y2 in 2005
Soy	Soy	10	87	87	7.57	72.032	5.453
Soy	Corn	75	87	26	16.97	72.032	12.224
Corn	Soy	70	26	87	15.83	81.779	12.946
Corn	Corn	20	26	26	1.35	81.779	1.104
TOTAL							31.727

There are four scenarios for planting a Roundup Ready (RR) corn or soybean crop in two successive years (Y1 and Y2): RR soy or RR corn in both years, RR soy to RR corn, or RR corn to RR soy. For each scenario, we first apply USDA crop rotation data to estimate the percentage of total Y1 crop acres that are planted to the Y2 crop the next year (Rotation Factor Y1 to Y2 Crop). For instance, 75% of soybean acres in Y1 are planted to corn in Y2. We then apply Roundup Ready Adoption Factors for the percentage of total corn and soybean acres that are Roundup Ready in Y1 and Y2, based on USDA GE herbicide-resistant crop adoption figures for 2005 (see Figure 6 for source). The product of these three factors gives the RR Rotation Factor. This represents the percentage of total Y1 crop acres that are planted to Roundup Ready varieties in both Y1 and Y2 for the given scenario. This figure is then multiplied by total Y1 crop acres to give the acreage planted to a RR crop in both years for the scenario. The acres for each of the four scenarios is then added to give total acreage planted to a RR crop in successive years.

It should be noted first that this simulation accounts for soybean and corn acres that are rotated to other crops (e.g. wheat, cotton, sugar beets, canola, alfalfa). It is assumed that 85% of Y1 soybean acres are rotated to either soybeans (10%) or corn (75%), meaning 15% are rotated to some other crop. Likewise for corn, 70% (corn to soybeans) and 20% (corn to corn) leaves 10% of corn acres rotated to other crops. Because nearly all cotton, sugar beets and canola, and a rising percentage of alfalfa, are Roundup Ready, the simulation is conservative in excluding RR versions of these crops as rotation partners for RR corn/soybeans. Second, the 2013 RR Adoption Factor for soybeans has been adjusted from 93% to 89% to account for the 4% of national soybean acres planted to LibertyLink (glufosinate-resistant) varieties in that year.²

² As noted in the body of the report, the 93% of soybean acres planted to herbicide-resistant varieties in 2013 is comprised of 89% Roundup Ready and 4% LibertyLink. We did not make a similar correction to account for LibertyLink (LL) corn because we lack reliable figures on LL corn adoption; LL corn adoption has always been low, as indicated by NASS Agricultural Chemical Usage figures showing that <5% of corn acres have been treated with glufosinate over the period assessed here (e.g. 2% in 2010); and any glufosinate-resistant corn planted today is likely Monsanto's SmartStax corn, which is resistant to glyphosate as well as glufosinate.

Excerpt From USDA Agricultural Chemical Usage Report for 2005

**Soybeans: Agricultural Chemical Applications,
Program States, 2005¹**

Active Ingredient	Area Applied	Appli- cations	Rate per Application	Rate per Crop Year	Total Applied
	<i>Percent</i>	<i>Number</i>	<i>Pounds per Acre</i>	<i>Pounds per Acre</i>	<i>1,000 lbs</i>
Herbicides					
2,4-D, 2-EHE	4	1.0	0.440	0.440	998
2,4-D, BEE	1	1.0	0.436	0.436	298
2,4-D, dimeth. salt	1	1.0	0.501	0.501	243
Atrazine	*	1.0	3.257	3.257	542
Chlorimuron-ethyl	4	1.0	0.013	0.013	34
Clethodim	3	1.0	0.086	0.086	156
Cloransulam-methyl	1	1.1	0.032	0.034	31
Dicamba, Digly Salt	*	1.0	0.263	0.263	40
Fenoxaprop	2	1.0	0.032	0.032	31
Fluazifop-P-butyl	2	1.0	0.109	0.109	125
Flumiclorac-pentyl	1	1.0	0.013	0.013	7
Flumioxazin	3	1.0	0.061	0.062	105
Fomesafen	3	1.0	0.247	0.247	411
Glyphosate	3	1.2	0.861	1.020	1,683
Glyphosate iso. salt	88	1.5	0.755	1.101	63,047
Imazamox	*	1.0	0.028	0.028	6
Imazaquin	1	1.0	0.099	0.099	39
Imazethapyr	2	1.1	0.050	0.057	85
Lactofen	1	1.0	0.128	0.128	57
Metribuzin	2	1.0	0.148	0.148	204
Paraquat	*	1.0	0.479	0.479	151
Pendimethalin	3	1.0	0.968	0.968	2,123
Quizalofop-P-ethyl	*	1.0	0.052	0.052	8
S-Metolachlor	1	1.0	0.951	0.951	549
Sulfentrazone	2	1.0	0.083	0.083	131
Sulfosate	2	1.5	1.162	1.752	2,681
Thifensulfuron	2	1.0	0.005	0.005	6
Trifluralin	4	1.0	0.782	0.782	1,791
Insecticides					
Acephate	*	1.4	0.603	0.826	220
Chlorpyrifos	5	1.0	0.477	0.482	1,413
Cyfluthrin	*	1.4	0.026	0.038	8
Esfenvalerate	1	1.1	0.040	0.043	25
Lambda-cyhalothrin	6	1.0	0.023	0.023	88
Permethrin	1	1.0	0.122	0.122	67
Zeta-cypermethrin	1	1.0	0.024	0.024	19
Fungicides					
Azoxystrobin	1	1.0	0.100	0.100	57
Pyraclostrobin	1	1.0	0.104	0.104	80
Tebuconazole	*	1.0	0.177	0.177	48

* Area applied is less than 0.5 percent.

¹ Planted acreage in 2005 for the 17 Program States was 64.8 million acres.

States included are AR, IL, IN, IA, KS, KY, LA, MI, MN, MS, MO, NE, NC, OH, SD, TN, and VA.

Source: USDA NASS (2006). Agricultural Chemical Usage: 2005 Field Crops Summary. USDA National Agricultural Statistics Service, May 2006, p. 97.

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