Glyphosate and Green politics: Rounding up the evidence

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Introduction

Glyphosate is the active ingredient in the many proprietary herbicides that are widely used by gardeners, in public spaces and, most importantly, by farmers to suppress and kill weeds. All herbicides have implications for public health, especially when instructions for their proper use are ignored. Glyphosate has probably been exposed to more scrutiny and debate than any other pesticide since the insecticide DDT, the dangers of which were brought to public attention by Rachel Carson in her classic 1962 book *Silent Spring*.

The substantive focus of this article is on glyphosate use in agriculture and its possible effects on human health. Evaluations of the safety or otherwise of herbicides depend, in part, on the proper application of statistical methods as well as on other scientific issues that are not covered here. Hence, an important underlying theme of this article is the availability, quality and the use made of statistical evidence in scientific debates of all kinds. Unfortunately, as we shall see, the glyphosate debate is littered with ignorance of available statistics, conceptual confusion and misuse of statistical methods.

Glyphosate was first marketed by the US agri-business company Monsanto in Roundup. Roundup is manufactured in the UK under licence from Monsanto. Since coming out of patent in 2000, there are, however, many other herbicides on the market which contain glyphosate in varying strengths and often mixed with other chemicals intended to improve performance. One consequence of this variability is that any assessment of the safety of glyphosate will have implications for the safety of these different commercial herbicides without necessarily covering the safety of all their constituent parts.

A lot of the debate about glyphosate is in fact a proxy for a debate about genetically modified or engineered (GM or GE) crops. Nearly all of the two major crops grown in the US – corn (maize) and soybeans – use GE seeds developed by Monsanto which make these two crops resistant to the application of glyphosate and are known as Roundup Ready (RR) corn and soy[1]. In other words, glyphosate can be applied to these crops as they are growing to suppress weeds without damaging the crop (National Academies of Sciences, Engineering, and Medicine, 2016, p. 49), with the expectation that this will have advantages both in terms of reducing agricultural inputs and increasing yield. GE crops are subject to a barrage of criticism from many quarters. Although the GE debate is not the main topic of this article, some reference to it is unavoidable.

The article starts with a description of some trends in herbicide and glyphosate use by farmers in the UK and USA. Despite an EU directive in 2009 (Directive 2009/128/EC) to establish a framework for Community action to achieve the sustainable use of pesticides, which includes a section (Article 15) on collecting statistics, EU-wide statistics remain patchy and based on overall pesticide sales and not on pesticide use by farmers and others. The UN Food and Agriculture Organisation (FAO) also bemoans the absence of pesticide use statistics from many countries. The omission is particularly noteworthy in the cases of Argentina and Brazil where RR crops, soy especially, are so widely grown.

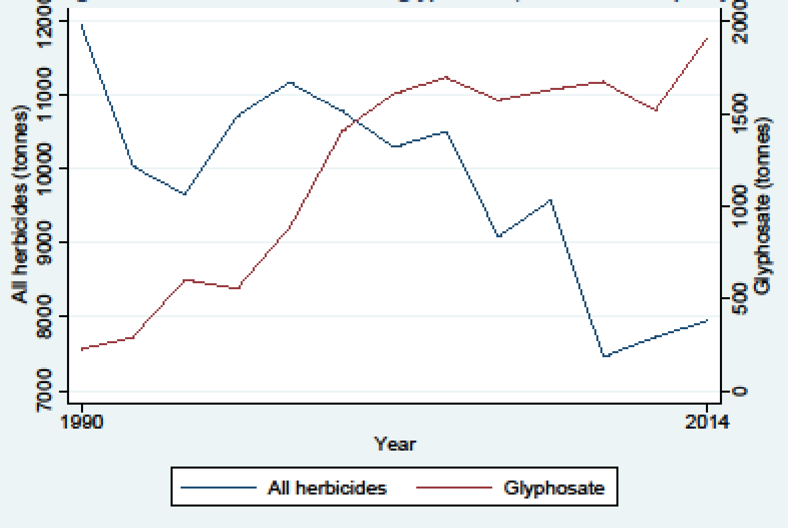
This is followed by an examination of the statements by international associations and regulatory agencies about the safety of glyphosate. I then critically examine one set of contributions to the glyphosate debate from scientists who are approvingly quoted by Green pressure groups. The final section puts these debates about evidence into a broader European political context and considers whether some of the arguments made by Green groups, and their consequent actions, might be counter-productive in terms of the many risks to the environment that arise from growing the crops that are needed, both now and in the future, to sustain and improve life for everyone on the planet.

Trends in glyphosate use

The UK's Pesticide Use Statistics (PUS) are produced from pesticide usage surveys that are commissioned by the independent Expert Committee on Pesticides. Data are collected by the Pesticide Usage Survey teams at Fera Science Ltd (formerly the Food and Environment Research Agency), the Scottish Agricultural Science Agency and the Agri-Food and Biosciences Institute of Northern Ireland. They are funded by the pesticides charge on turnover and costs are paid to Fera Science Ltd by the Chemicals Regulation Division (CRD) of the Health and Safety Executive (HSE). They are designated as National Statistics[2]. In recent years, some of the data have been supplied by a commercial market research firm, Kynetec, from a panel of farmers that they maintain (Garthwaite et al., 2015)[3]. This reliance on a private company does raise concerns as Kynetec provide very little information to users of the statistics about their target population, sampling methods, what decisions influence movements in and out of their panel, response rates etc.

We see from Fig. 1 that, between 1990 and 2014[4], the trend, albeit somewhat erratic, is for farmers in Great Britain to use all herbicides less intensively on arable crops in terms of weight[5]; glyphosate use – the focus of this paper - has, however, increased considerably in that period. As a proportion of the weight of all herbicides used, glyphosate has risen steadily from less than 2% in 1990 to nearly a quarter in 2014. Over 90% of the land growing arable crops was treated with herbicides throughout the period in question; for glyphosate, the corresponding percentage has risen from about five in 1990 to over 30 in 2014. There has also been a trend to use herbicides more frequently throughout the growing season but to apply them more sparingly at each application.

Fig. 1: Use of all herbicides and glyphosate; UK arable crops by year



We can get a clearer picture of trends for both all herbicide and glyphosate use (by weight) in Great Britain by disaggregating arable crops into their component parts: cereals (which take up the majority of land devoted to arable crops and account for between 55% and 81% of the weight of all herbicides used), oilseeds, potatoes, peas and beans, and beets. We can also smooth out some of the fluctuations from survey to survey by (i) modelling herbicide use as a function of year by fitting a simple regression model to weight of herbicide used (in tonnes) with acreage[6] and year (n = 13) as the two explanatory variables; (ii) fitting lowess[7] curves (available on request) to rate (kg/hectare) of herbicide use[8]. The advantages of (i) are that interpretation is easier and model diagnostics can be used. On the other hand, fitting regression models can give too much weight to the end points of the time series and so a local smoother can provide more insight into the underlying trends.

We see from Table 1 that the regression models fit well and, although the data come from a biennial time series, additional tests suggest there is no evidence of autocorrelation. The weight of all herbicides used has (a) declined with time for cereals with the lowess curve suggesting that this decline has become more marked in recent years, (b) remained essentially constant for beet crops (although the lowess curve, not shown here, suggests an increase in the last decade) and (c) increased for the other crops, notably oilseeds. Glyphosate use has, however, increased for each of the arable crop groups, perhaps flattening off for oilseeds.

Table 1: Estimated regression coefficients (s.e) [R^2] for year, UK herbicides

	All arable	Cereals	Oilseeds	Potatoes	Peas and Beans	Beet crops
All herbicides	-153 (61) [0.58]	-177 (66) [0.78]	74 (17) [0.89]	22 (4.5) [0.73]	9.6 (2.5) [0.91]	-12 (9.5) [0.87]
Glyphosate	136 (14) [0.92]	79 (11) [0.86]	48 (12) [0.86]	5.4 (1.3) [0.82]	13 (1.3) [0.90]	10 (3.4) [0.67]
Not glyphosate	-403 (57) [0.87]	-256 (61) [0.85]	26 (13) [0.83]	17 (5.2) [0.52]	-3.4 (2.1) [0.92]	-22 (11) [0.87]

Note

1. Each of the three sets of regression estimates give the expected change per year in tonnes of herbicide type used for fixed acreage.

One plausible implication of these patterns of use is that glyphosate has been substituted for other herbicides within the general context of a reduction in weight of herbicide use for cereal crops and that, as farmers started to use glyphosate more for cereals, they also increased herbicide (and glyphosate) use for oilseeds, potatoes, and peas and beans. This is supported by the comparison between the estimated regression coefficients for 'glyphosate' and 'not glyphosate' in Table 1.

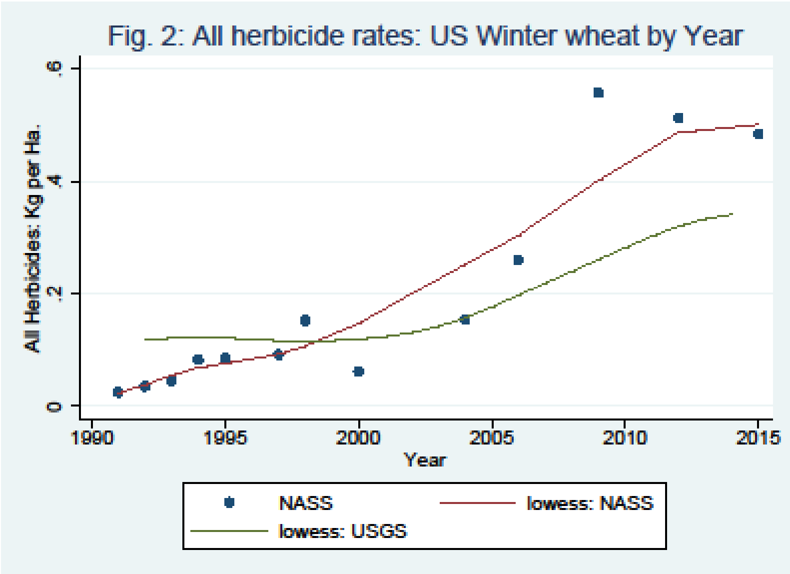
We can also examine what has been happening to cereal crops in the United States where the agricultural context is very different. In particular, a lot of the debate about glyphosate in the US is as much or more a debate about GE crops which are not currently grown commercially in the UK (and hardly elsewhere in Europe). However, wheat is one US crop that does not, at present, use GE seeds.

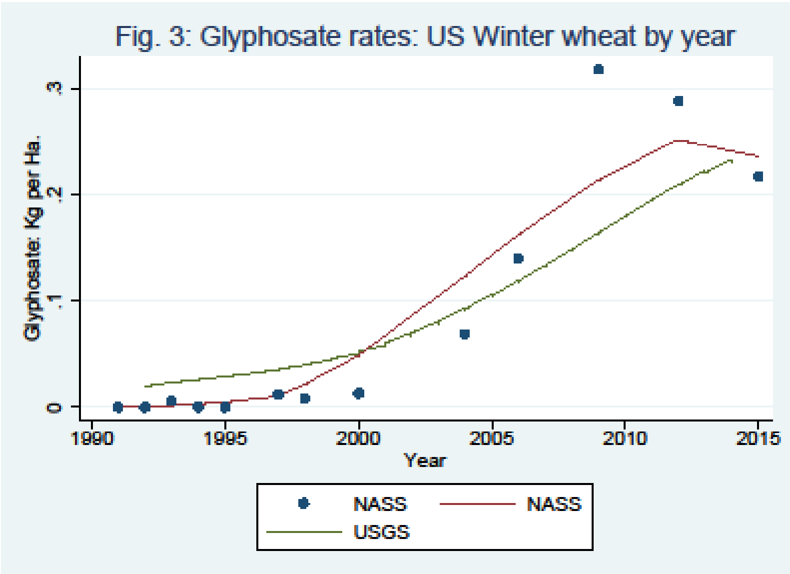
There are two main sources of time series data about pesticide use on different crops in the US. The first is the National Agricultural Statistics Service (NASS) from the US Department of Agriculture (USDA), the second comes from the US Geological Survey (USGS)[9]. Briefly, the NASS time series are based on an annual survey during the 1990s but a less frequent survey in recent years. The gaps in the series after 2000 make it more difficult to discern recent trends. On the other hand, the NASS surveys do use probability sampling methods. The USGS data come from annual surveys carried out by Kynetec with many of the same issues of a lack of methodological transparency noted with regard to the PUS statistics in the UK. Different kinds of wheat (e.g. winter and spring wheat) are separated in the NASS data but not in the USGS data. The two data sets do, however, tell essentially the same story when we look at trends. Table 2 is based on the same model used for the UK data and shows that the use of all herbicides and glyphosate by weight is increasing with the USGS data series suggesting that this increase is gaining pace (as the quadratic term in year is important for both USGS series). The lowess curves in Figs. 2 and 3 are based on a core group of five US states where practically all the wheat grown is winter wheat[10] and so the NASS and USGS time series are more comparable. They paint a similar picture: increasing use of glyphosate and all herbicides for both data sources, albeit at different rates and with differences in level, especially for all herbicides where the USGS rates are lower[11].

Table 2: Estimated regression coefficients (s.e) [R^2] for linear and quadratic terms in year[1, 2], US herbicides

	All wheat		Winter wheat
	USGS (high)	USGS (low)	NASS
All herbicides	190 (49); 7.1 (3.6) [0.75]	151 (39); 7.9 (2.8) [0.81]	479 (84) [0.90]
Glyphosate	139 (26); 8.3 (1.7) [0.94]	132 (23); 8.5 (1.6) [0.95]	305 (58) [0.89]

<u>Notes</u>
1. Year centred at year 2000.
2. Linear and quadratic terms in year are only needed for USGS data; the first estimate in each row is for the linear term, the second is for the quadratic with the corresponding standard errors below.
3. USGS provide two estimates – 'high' and 'low'. The former includes adjustments based on data from neighbouring areas in cases of zero reported use, the latter does not.
4. See note to Table 1 for interpretation of the estimates.





Farmers have applied more and more glyphosate to their main crops over the last twenty five years, both in the UK and in the US (and probably in many other countries where time series data are not available). And it is likely that nearly all farmers in developed countries control weeds chemically and are unlikely to stop doing so. But applying more glyphosate does not necessarily mean increasing the chemical burden when controlling weeds. In the UK, overall weight of herbicides used on arable crops as a whole, and for cereals, has in fact declined since 1990. In the US on the other hand, herbicide use has increased for wheat. Herbicides are not, however, homogeneous; they vary in their environmental impact and any assessment of their effects needs to take this into account (National Academies of Sciences, Engineering, and Medicine, 2016, p. 86). Glyphosate is effective and increases farmer productivity. It is also widely believed (e.g. Kniss, 2017) to have less of an impact on health and the environment than other herbicides whose use has declined as glyphosate use has increased. Is glyphosate safe?

Safety assessments

The controversy about the safety of glyphosate has been rekindled by a recent assessment from the International Agency for Research on Cancer (IARC). IARC (2015) gave a class 2A classification to glyphosate: 'probably carcinogenic to humans'. This classification has received considerable critical attention from researchers and commentators as well as a lot of publicity in the media. There are two main strands to the criticisms of IARC. The first is that, even in their own terms, IARC did not always satisfactorily assess the evidential value of the many studies available to them: Tarone (2016), a cancer statistician, is a strong critical example here.

The other strand is arguably the more germane for this article and relates to the important but subtle distinction between *hazard* and *risk*. 'Risk' takes the dose into account, 'hazard' does not. In other words, a substance can be hazardous in some circumstances but this does not imply that it is a risk at all doses or exposures. The IARC approach leads them to assess the hazards of different aspects of life. Thus, for example, sunlight is classified by IARC as a class 1 carcinogen: 'carcinogenic to humans' (and thus more dangerous than glyphosate). Of course, prolonged exposure to sunlight can be dangerous but some exposure is necessary in terms of vitamin D intake. A similar issue arises with glyphosate – it could be dangerous at extreme doses but the evidence from regulatory bodies (see below) suggests that it is not dangerous if used in accordance with herbicide manufacturers' instructions about dilution and protection. In other words, the evidence indicates that the risks from glyphosate are small once typical exposures are taken into account. This does raise the question of whether the IARC approach is fit for purpose given the media's propensity to seize on cancer scares whenever they can. Boobis et al. (2016) give a detailed and historically based account of the strengths and weaknesses of the different ways of classifying carcinogens and are particularly critical of the IARC approach. What is clear is that the IARC classification of glyphosate has been, and continues to be widely promulgated without any consideration being given as to what the classification actually means in practice.

Another difficulty with the IARC classification is that it has led to disputes between them and regulatory bodies in Europe and North America. In Europe, EFSA (European Food Safety Authority) is the body responsible for assessing the health risks from pesticides. They appoint an organisation from one of the EU member states to carry out the assessment and, for glyphosate, this was the German BfR (Federal Institute for Risk Assessment). BfR's focus was on risk rather than hazard and EFSA (2015) concluded that 'glyphosate is unlikely to pose a carcinogenic hazard to humans and the evidence does not support classification with regard to its carcinogenic potential according to Regulation (EC) No 1272/2008.' Moreover, even the European Chemicals Agency – which assesses hazard rather than risk – concluded that the evidence did not meet the criteria for classifying glyphosate as a carcinogen (ECHA, 2017).

In the US, the Environmental Protection Agency (EPA) concluded that the category with the strongest support is "not likely to be carcinogenic to humans *at doses relevant to human health risk assessment*" (EPA, 2016, my italics).

Another difference between the approaches of IARC on the one hand, and EFSA and EPA on the other is that the latter assess only the effects of the active ingredient whereas IARC base their designation on herbicide formulations that include other chemicals. These differing methods lead to conflicting assessments that are unhelpful for citizens who wish to make reasoned judgments about glyphosate-based herbicides, a point I return to in the discussion. And it is important to recognise that all these health assessments are related solely to cancer; they do not cover the many other aspects of the public health.

Statistics in scientific debates

There have been many scientific papers about the effects of glyphosate on human health; the recent IARC report contains references to over 150 papers with glyphosate or Roundup in the title. Moreover, there are a number of reports on glyphosate residues in food, breast milk and urine, usually funded by pressure groups (Moms Across America; Food Democracy Now), which have rather unsound scientific foundations, are light on procedural and methodological details, and which seem designed as much to scare people as to inform them. There is, however, one research group – CRIIGEN at the University of Caen, France with Professor Gilles-Eric Séralini as its lead researcher – which has been especially active in this field over the last decade.

Their work is of particular relevance because it draws out the tension between the quality of peer-reviewed scientific research on the one hand and the publicity given to that research by the media and pressure groups on the other.

The work of the CRIIGEN group received international media attention with the publication of a paper in *Food and Chemical Toxicology* (Séralini et al., 2012, henceforth FCT). This was a multi-faceted feeding experiment with rats, one part of which examined the effects of three different doses of Roundup in the rats' drinking water. The three doses were: 1.1 x 10^{-8}% (i.e. very low); 0.09%; 0.5%. Note that the recommended dilution of Roundup for spraying on weeds is only 1% so the highest dose in this study (directly into the drinking water) is very high and likely to be far greater than any realistic human exposure, especially as the rats were exposed to this dose every day for, potentially, up to two years. The authors conclude that their results 'clearly demonstrate that lower levels of complete agricultural herbicide formulations, at concentrations well below officially set safety limits, induce severe…disturbances' (p.4230). The authors assume that disturbances in rats have implications for humans.

The FCT paper received an unusually large amount of criticism from scientists in the field: about the strain of rats used, the small samples in the experimental groups and, to a lesser extent, the statistical methods used (or, more to the point, not used). These criticisms are well-documented and references to them can be found in Wikipedia (The Séralini Affair; https://en.wikipedia.org/wiki/S%C3%A9ralini_affair). The IARC (2015, p.35) concluded that the study 'was inadequate for evaluation'. Anne Glover, the EU's chief scientific advisor at the time, described the study as 'hopelessly flawed' (http://www.euractiv.com/section/science-policymaking/news/chief-eu-scientist-backs-damning-report-urging-gmo-rethink/). The criticisms were sufficiently numerous and powerful that the paper was retracted by the journal in 2013 only to be republished by *Environmental Sciences Europe* in 2014 (Séralini et al., 2014).

The main statistical defect of the FCT paper is that the authors did not make any attempt to determine whether the differences between their experimental groups were greater than would be expected by chance. Moreover, there is no evidence of the expected dose response relationship, with tumour incidence and death usually lower at the highest Roundup dose, and no suggestion that a non-monotonic dose response relation was hypothesised. Nor was there any recognition that tumours are likely to be clustered within rats, something that needs to be taken into account in any analysis of tumour incidence. The FCT paper does have a section on statistical analysis but it is mindboggling in its opacity and irrelevance as indeed is the authors' response to their critics. Much of this could have been avoided if the paper had been sent to a statistician for review but it was not. The decision to retract the paper was based on flaws in the paper which should have been picked up in the refereeing process. On the other hand, a failure of the peer review process is not, in my view, sufficient justification for a paper to be retracted. However, the editors of the republishing journal - *Environmental Sciences Europe* – were also culpable in that they did not submit the paper for further peer review. One consequence of these actions is that Séralini became, and continues to be a hero for Green and anti-GE pressure groups, portrayed by them as the honest scientist battling against corporate interests as represented by Monsanto.

Since the FCT paper, the CRIIGEN group and their collaborators have published three further papers on Roundup with, in principle, implications for aspects of human health other than cancer: Mesnage et al., 2015 (EH) and 2017 (SR), and Gress et al., 2016 (CAM)[12]. The EH paper is based on the same experiment reported in the FCT paper, deals with gene disturbances but only reports for females and, surprisingly in the light of the absence of a dose response relation in the FCT paper, only for the lowest dose of Roundup. They conclude that 'chronic exposure to a glyphosate-based herbicide…at an ultra-low environmental dose can result in liver and kidney damage with potential significant health implications for animal and human populations'. The authors did use some methods of statistical inference in this paper but they did not address the unit of analysis problem; there is likely to be clustering of gene disturbances in rats just as there will probably be clustering of tumours. Ignoring this clustering leads to comparisons which do not properly allow for chance. There are a number of other unsatisfactory aspects of the paper (see Plewis, 2015). An important point to be aware of here is that this journal does publish the reports of the referees. These referees were asked whether the paper should be referred to a statistician and both said no, despite the fact that some quite advanced methods were used. Again, we see a failure of the peer review system.

The SR paper uses the same sample of female rats and the same dose of Roundup as the EH paper and focuses on liver disease. Again, the validity of their conclusions is compromised by missing data and outliers. The study was funded by the Sustainable Food Trust, an admirable organisation in many ways but one which is opposed to the use of all chemicals in agriculture.

The CAM paper is another rat feeding study, partially funded by Sevene Pharma, a French company involved in the manufacture of homeopathic remedies. The main aim of the paper was to see whether a particular homeopathic preparation based on plant extracts (Digeodren) protects against dysfunctions supposed to be caused by Roundup. This paper is also based on just one dose of Roundup but this time it's the highest of the three doses in the FCT paper given for a period of eight days; we are not told why. They conclude that 'Our results evidence the reversal, by specific plant extracts, of some of the adverse effects provoked by Roundup' (p. 6). These adverse effects included reduced locomotor activity and changes in liver and kidney parameters. Leaving aside the questions of (a) whether a homeopathic remedy is likely to affect anything, and (b) the conflict of interest arising from the sponsors of the study, we again find that the paper is replete with methodological holes, something that we can establish because the authors made their data available in an additional file. The study was set up with 40 rats in each of four experimental groups. The results for locomotor activity are based on 24 rats in each group with no explanation of how these rats were selected. Biochemical tests were performed purportedly on 10 rats per group but sometimes only eight; sexual hormones were said to be measured on 20 rats per group but sometimes only 16. Again, there is no discussion of the selection and missing data mechanisms involved. And again, these rather obvious deficiencies were not picked up by the referees.

One important aspect of all four of the papers from CRIIGEN is that they study Roundup and not its active ingredient, glyphosate. It is not clear whether their results are affected by the other chemicals found in Roundup as they make no attempt to isolate these. And they do vary in the way they refer to Roundup; sometimes as a trade name, sometimes as a representative of all glyphosate based herbicides and sometimes as glyphosate itself.

To summarise the statistical deficiencies of the CRIIGEN papers, we have seen how they ignore fundamental issues of statistical inference including the importance of clustering within experimental animals (FCT and EH), how they are not transparent in their discussion of selection and missing data (CAM and SR), how they gloss over issues of dose response relations (all four papers) and how they use obscure statistical methods to obfuscate rather than to illuminate (FCT). Despite these damaging frailties, Séralini's research is still widely and positively referenced by Green groups and politicians, e.g. Corinne Lepage, former French Minister of the Environment.

The papers from CRIIGEN also raise another issue that has concerned statisticians for many years: the quality of statistical evidence in scientific journals. It is clear that many journal editors are not seeking statistical advice as often as they should and that scientific referees are not able to recognise that statistical advice is needed, even for what appear on the surface to be rather straightforward papers. Consequently, papers are being published in the peer-reviewed literatures that are statistically deficient. This raises difficulties for all of us who rely on the peer review system to filter out poor quality papers. Scientific commentators, pressure groups and politicians cannot be blamed if they accept findings in peer-reviewed journals at face value. Nor can they always be expected to know which are the good journals in a discipline, and which are not much more than vanity publishing or 'pay to play' journals.

Discussion

The glyphosate controversy brings out a number of issues that should concern us as statisticians and as citizens: about the ways data are collected or not collected; about transparency of method; about the ways our methods are used, not used or abused, and about the ways statistical evidence is interpreted, misinterpreted or ignored. Unfortunately, statistical lights do not shine brightly on the glyphosate debate. One reason for this is that campaigners have bound glyphosate so closely to GE crops that reasoned arguments about glyphosate are lost in the arguments against GE. Yet we have seen (in the second section of the paper) that we can separate glyphosate use from GE crops both in the UK and, for wheat, in the US.

It is clear that in order to assess the changing pesticide landscape, we need good data over time on pesticide use, disaggregated by crop, active ingredient and region. There is evidence to support those campaigners against glyphosate who assert that rates of use are increasing on agricultural land as a whole although, as always in statistical analysis, a more nuanced picture comes when we break the picture down into component parts. Unfortunately, few countries collect the data needed and thus it is almost impossible to get a clear picture of trends in Europe and certainly not globally. The UK statistics on pesticide use are, arguably, the best in the world, not least because they form a sufficiently long time series to be able to discern some important trends.

There is, however, a worry that the part-privatisation of these statistics will have a negative effect on their quality. Kynetec's surveys on pesticide use are becoming a key resource on pesticide use, not only in the UK and US but also in developing countries. They are not, however, a public resource and Kynetec appear not to recognise any obligation to publish anything more than the skimpiest details about their methods. We simply do not know whether they would stand up to statistical scrutiny – about their sampling methods, their ways of dealing with non-response, their strategies for dealing with panel maintenance etc.

We have seen how evidence about hazard does not translate into evidence about risk. Glyphosate might be hazardous but the bulk of the evidence indicates that the level of risk attached to it need not concern us. Rather we find (from the reports of the regulatory authorities discussed in the third section), a paucity of convincing evidence about the deleterious effects of glyphosate on human health. The distinction between hazard and risk has been clearly and widely spelt out by scientists since the IARC report but is wilfully ignored by some Green groups. Thus we find Greenpeace proclaiming **"Monsanto's super popular weed killer, Roundup, probably causes cancer!"** as part of a campaign to have it banned. Apart from the misrepresentation of risk, what this ignores is (i) glyphosate is found in many products; (ii) many farmers in the developed world use herbicides and, if glyphosate were banned, they are likely to turn to other herbicides that are arguably more deleterious to the environment (Kniss, 2017); (iii) farmers might rely more on ploughing and other practices that also have undesirable consequences in terms of carbon release and (iv) farmers in poorer countries might be discouraged from using such a relatively benign herbicide and so lose a much needed opportunity, ideally within the context of integrated weed management - http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/scpi-home/managing-ecosystems/integrated-weed-management/iwm-what/en/ - to increase crop yields. To give just one example relevant to this last point, Rodenburg et al. (2016) estimate that parasitic weeds affect rice production in sub-Saharan Africa to such an extent that annual economic losses exceed US$100 million.

Although, as I argue here, the current evidence against glyphosate, especially its effects on human health, is weak, there are issues that need to be kept under review and where more investigations are warranted (the registration review process of the US EPA is designed to do just that). Concerns about the emergence of weeds resistant to glyphosate – so-called 'superweeds' – are well founded although resistance to any herbicide will occur if it is over-used. And pesticides of all kinds, including those used by organic growers, carry an element of risk to the wider environment, risks which need to be monitored and revised as new evidence emerges. Moreover, there is understandable suspicion about the motives of large agri-business companies in terms of their marketing strategies and the extent to which they suppress evidence about the environmental effects of their products. There can be no doubt that Roundup, in combination with RR crops like corn and soybeans, has generated enormous profits for Monsanto. And, if the proposed takeover of Monsanto by the German chemical giant Bayer goes ahead, then there is a justifiable concern that the world's food supplies will, indirectly, be concentrated in just a few global corporations.

Unfortunately Green politicians, especially the Green group in the European parliament, and international Green pressure groups are too easily drawn to their Great Satans, Monsanto and GE crops, instead of assessing the status of the evidence against glyphosate and of assessing what the economic and social costs would be if it were banned. There are arguably much more important agricultural practices that need to be addressed if a world of nine or more billion people is to feed itself – land degradation, devoting so much land to growing crops just to feed animals, and developing crops that are robust to the effects of climate change being just some of these. A particularly egregious example of misplaced effort was the recent "Monsanto Tribunal" (http://www.monsanto-tribunal.org/), essentially a show trial in which Monsanto was accused of ecocide, where the judges were appointed by the prosecution, where parts of the evidence consisted of dubious anecdotes by people who claimed to have become ill after being exposed to glyphosate, and where no cross-examination by the defence was allowed. Professor Séralini and Corinne Lepage were both members of the steering group for this event. The scientists and lawyers who got involved in it could surely have found better uses of their time, and the Green groups who funded it might have used their money more wisely.

Conclusion

We need good data, and well-designed and analysed studies on the use and effects of herbicides and other pesticides. And these data should be produced and made public in a transparent way. This applies as much to the multinational companies as it does to academic researchers. The recent decision by **EFSA to share the raw data that was used in its safety evaluation of glyphosate, albeit only with a group of MEPs who submitted an official request to see the information, is therefore to be welcomed.** We also need a more honest debate about the costs and benefits of herbicides like glyphosate and to stem the tide of misinformation. At a time of such pressing environmental concerns, and when the value of evidence and expertise is constantly being undermined, Green groups and journalists might reasonably be expected to critically examine their own roles in how public debates of this kind are conducted.

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Notes

1. The other important commercial application of the technology is in so-called Bt crops where the seeds are modified to express an insecticide (Bacillus thuringiensis) which kills certain kinds of insects. In corn, RR and Bt technologies are widely combined in seeds.

2. 'National Statistics' are a subset of official statistics which have been certified by the UK Statistics Authority as compliant with its Code of Practice for Official Statistics.

3. The UK pesticide use statistics also cover 'amenity' use, not considered here. In 2012, over four times as much glyphosate, and 11 times as much of all herbicides (by weight), was used on crops as on amenity use (which was mostly on railways and motorways).

4. Surveys of arable crops took place biennially in the evenly numbered years.

5. Between 1990 and 2014, arable crops accounted for between 83% and 92% of all crops covered by PUS by area and between 74% and 90% of all herbicides applied by weight.

6. The acreage data come from DEFRA:

https://data.gov.uk/dataset/june_survey_of_agriculture_and_horticulture_uk/resource/14594f48-af59-422a-8230-5dc33405d286

They refer to the UK as a whole whereas the PUS refer only to GB. However, Northern Ireland accounts for < 1% of all UK arable crop area.

7. Lowess: locally weighted scatterplot smoother. I used STATA for this.

8. It is usual to measure herbicide use in terms of weight per area (e.g. kg/hectare) although weight per yield might be an alternative, especially for insecticides and fungicides that are applied directly to a crop rather than to the ground.

9. These data can be found at:

NASS:https://www.nass.usda.gov/Statistics_by_Subject/Environmental/index.php

USGS: https://water.usgs.gov/nawqa/pnsp/usage/maps/county-level/

The strengths and shortcomings of these two data sets are set out in a short paper available on request.

10. These five states – Colorado, Kansas, Nebraska, Oklahoma and Texas - account for about 60% by area of all winter wheat grown.

11. These results are consistent with those in Kniss (2017) who used only USDA data and a different outcome measure.

12. The abbreviations refer to the title of the relevant journal.

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