A review and assessment of 'Impact of genetically engineered crops on pesticide use in the US – the first sixteen years: Benbrook C (2012)' –Environmental Sciences Europe vol 24: 24 (September 2012)

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1 General observations and criticisms

This paper makes a number of broad claims relating to negative health and environmental impacts associated with the use of genetically modified/genetically engineered (GM/GE[1]) crops in the US. These changes, the author claims, are caused by the widespread adoption of GM crops and to *'the growing number and geographical spread of glyphosate-resistant weeds'*. The author goes on to claim that:

- The basis for his conclusions derive from analysis of official United State Department of Agriculture (USDA) pesticide use data;
- That there are few comprehensive estimates of the impacts of GM HT crops on herbicide use and that;
- Other analysts are wrong when they examined the impact of pesticide use change with GM crops in the US and came to completely different (opposite) conclusions to him.

For those reviewing the issues examined in the Benbrook (2012) paper, the following summary points should be noted:

- *Inaccurate claim:* In the press release for Benbrook (2012) the author claimed that this is the first peer reviewed paper to examine pesticide use changes with GM crops in the US. There have been numerous papers by other analysts that have examined this issue in peer reviewed papers. The first named author of this review and assessment document for example, has written thirteen peer reviewed papers on the impact of GM crops, nine of which examined pesticide use changes with GM crops and all of which pre-date Benbrook (2012)[2];

- *Confirmation of GM insect resistant (GM IR) impact on insecticide use*: Benbrook (2012) confirms the (consistent) findings of other analysts' work that the use of GM IR technology has resulted in important reductions in insecticide use on these crops that would not have occurred with conventional technology;

[1] In all subsequent references in this document, the abbreviation GM is used

[2] It is also interesting to note that Benbrook (2012) does not refer to, or cite, a National Research Council report of 2010, which included detailed examination of pesticide use changes with GM crops in the US. This NRC report includes an acknowledgement of the input of Benbrook C as a reviewer

- *Failure to acknowledge the environmental benefits arising from use of genetically modified herbicide tolerant (GM HT) technology*. There is no discussion in Benbrook (2012) of the facilitation role of GM HT technology in helping many farmers in North (and South) America adopt no/reduced tillage production systems[3] which has resulted in important reductions in greenhouse gas emissions. For example, US GM HT crops contributed, in 2010, to the equivalent of removing 11 billion pounds (5 billion kg) of carbon dioxide from the atmosphere or equal to removing nearly 2.25 million cars from the road for one year. In addition, whilst usage of broad spectrum herbicides, notably glyphosate (and to a lesser extent glufosinate) has increased significantly, usage of less environmentally benign products such as pendimethalin, metribuzin, fluazifop and metalochlor has fallen substantially, leading to net benefits to the environment[4];

- *Inaccuracies and biased assumptions*: Benbrook (2012) uses assumptions relating to herbicide use on US crops that do not concur with actual (or recommended) practice. As a result, he overstates herbicide use on, for example, US GM HT soybeans and significantly understates use on conventional (non GM) crops;

- *Misleading use of official data:* Benbrook (2012) states in several places that the pesticide impact data are based on official, government (USDA) pesticide usage data. Whilst a USDA dataset is used, its limitations (namely not covering pesticide use on some of the most recent years and not providing disaggregated breakdowns of use between conventional and GM crops) mean that the analysis presented in Benbrook (2012) relied on his own interpretations and extrapolations of usage and cannot reasonably claim to be based on official sources. In particular, the herbicide usage assumptions on conventional crops, if they replaced GM HT traited crops, are significantly understated and unreliable. It is therefore not surprising that Benbrook (2012) concluded that GM HT crop use in the US resulted in an increase in US herbicide use. This contrasts sharply with the findings of other peer reviewed analysis[5] that estimated that GM crop adoption in the US reduced pesticide spraying in the US, eg, by 542 million lbs (246 million kg: -9.6% 1996-2010)[6] relative to what might reasonably be expected if the crops were all planted to conventional varieties.

2 Specific observations and criticisms

Background section

In the 'scene setting' section of the paper, Benbrook (2012) makes a number of broad claims relating to negative health and environmental impacts associated with the use of GM crops in the US (all lacking in citations/references to support the claims). These claims are largely attributed to *'the growing number and geographical spread of glyphosate-resistant weeds'*. Benbrook goes on to claim that the bases for his conclusions derive from analysis of official USDA pesticide use data, that there are few comprehensive estimates of the impacts of GM HT crops on herbicide use and that other analysts who have examined the impact of pesticide use change with GM crops in the US and come to

[3] And more importantly the staying in a reduced/no till systems

[4] For example, as recognised by Sullivan D et al (2009)

[5] Brookes G and Barfoot P (2012) Global Impact of Biotech Crops: Environmental Effects, 1996-2010, GM Crops 3: 2 April-June 2012, p 1-9. Available on the worldwide web at www.landesbioscience.com/journal/gmcrops

[6] Updating this analysis to include 2011, and applying to the GM crop planting data used in Benbrook (2012) suggests that the adoption of GM crop technology resulted in a net reduction in pesticide active ingredient use on the US GM crop area between 1996 and 2011 of about 573 million lbs (260 million kgs)

completely different (opposite) conclusions to him, are wrong. On all three counts, Benbrook (2012) is factually inaccurate (and disingenuous to both other analysts and the USDA) because:

- Firstly, his analysis derives from personal interpretations about pesticide use on GM versus conventional crops. It is not official USDA data;
- Secondly, there have been a number of other analysts that have examined in detail herbicide (and insecticide use) use changes with GM crops in the US. Benbrook (2012) chose only to discuss (and summarily dismiss) one such study (reference 6: Sankula S (2006) without discussing the methodology applied by Sankula S (2006);
- Thirdly, Benbrook (2012) dismissed other analysts work that identified reductions in pesticide use in the US with GM crops, as 'purported claims', even though these other analysts publications, are found mostly in peer reviewed literature that is both current and pre-dates Benbrook (2012).

Benbrook (2012) also makes a claim in the introduction that reductions in insecticide use associated with the adoption of GM IR corn *'are now in jeopardy as a result of the emergence of corn rootworm populations resistant to the Cry 3Bb1 toxins expressed in several corn hybrids'* (based on cited reference 1: Gassmann A et al (2011)). Benbrook (2012) goes on to state that '*to combat this ominous development, some seed and pesticide companies are recommending a return to use of chemical soil insecticides as a resistance management tool. There is a degree of irony in such recommendations, given that the purpose of Cry 3Bb1 corn was to eliminate the need for corn soil insecticides'.* In making these claims, Benbrook (2012) fails to place in context the impact of GM IR (resistant to corn rootworm) technology on insecticide use or the incidence of reported resistance to the technology in corn rootworm (CRW) populations. The adoption of GM IR (resistant to CRW) technology has resulted in a significant reduction in the use of soil-based insecticides in the US, with use of several of the 'least environmentally-friendly' insecticides now effectively removed from use (later acknowledged by Benbrook (2012) in table 12). In respect of farmers who have experienced unusual damage due to CRW (suspected resistance development), insecticide remediation is one of the recommended best management practices, though the primary recommendations are for the use of either crop rotation or the use of a pyramided GM IR (resistant to CRW through more than a single insecticidal protein targeted against the CRW) traited seed. What Benbrook (2012) fails to state is that the area of GM IR (resistant to CRW) traited seed for which unexpected CRW damage has been reported is very small (just 0.14% of the 37 million acres planted to Cry3Bb-containing CRW trait products in 2011). Therefore the net impact on any additional insecticide use that might occur as result of taking up this recommendation will be (and has been) minimal.

Results and discussion section

1. In the opening two paragraphs, Benbrook (2012) first presents estimates of average herbicide active ingredient use on the three crops of corn, cotton and soybeans (in pounds per acre) derived from USDA pesticide usage surveys. Data for 1996 and the latest available year are presented; namely 2010 for corn and cotton, and 2006 for soybeans. Having presented this in the first paragraph, the second paragraph 'jumps' to the author's primary and key (claimed) estimate in the paper of how much herbicide use on these three crops has increased as a result of the widespread adoption of GM HT crops, largely tolerant to the active ingredient

glyphosate - an estimate of an increase in herbicide active ingredient use compared to the conventional alternative of 527 million pounds.

Several important points are omitted in this sub-section which are key, if readers are to a) understand how this estimate has been derived (and possibly builds on data presented in the first paragraph) and b) place the estimate in the context of changes in an equally important variable, the area planted to each of the three crops during the period 1996-2011. More specifically:

- That the values for average herbicide active ingredient usage per acre for all three crops for the years that the USDA did not undertake surveys (eg, 2003, 2007-2011 for soybeans) are based on the author's interpretation and extrapolation;
- That the values for average herbicide active ingredient usage per acre for the differentiated types of production (GM HT and conventional) <u>in all three crops in every year</u> (not just the years that USDA did not undertake surveys) are based on the author's own interpretations and assumptions;
- No baseline is provided for readers to judge the magnitude of the claimed 527 million pound increase in herbicide use;
- The context of planted area changes is ignored. This is important given the combined total planted area of the three crops in the US increased by 14% between 1996 and 2011. Comparing the authors own base for total active ingredient usage in 1996 (based on USDA data), his own assumption-driven estimates of total active ingredient usage in 2011 represents a 19% increase in total active ingredient usage over the 1996-2011 period. When compared to the change in the total area planted to the three crops (+14%), the resulting increase in active ingredient use claimed by Benbrook (2012) looks far less significant.

2. Benbrook (2012) seeks to justify the use of 'own interpretations and assumptions' for estimating herbicide use on the three crops (in total, and disaggregated by GM versus conventional) on the demise of USDA annual pesticide usage surveys in the mid 2000s due to government budgetary cuts, and goes on to claim that he has even applied conservative values for his assumptions. What this disingenuously denies readers is the provision of important information about other sources of data on herbicide use in the US on arable crops. The most comprehensive source of pesticide usage data on field crops in the US is from Gfk Kynetec, an independent, private market research source of farm-survey based data on agricultural input usage in the US[7]. This dataset goes back to 1998 and covers the period up to, and including 2011. As a source it is available to anyone who wishes to purchase the data[8] and therefore represents the most relevant, comprehensive and consistent source of pesticide usage data that Benbrook (2012) could have drawn on.

3. The Gfk Kynetec source not only covers pesticide use for all years from 1998, but also provides data disaggregated into usage on both GM and conventional crops. Drawing on this source of data, it is evident that Benbrook (2012) overstated herbicide active ingredient changes on the GM HT cropping areas for corn, cotton and soybeans by 53 million pounds for the period 1998-2011.

[7] Not an industry-sponsored dataset, as inaccurately described by Benbrook in an earlier (2009) paper

[8] And subject to some data-specific restrictions for onward publication

4. Even the Gfk Kynetec values for herbicide usage change with GM HT crop use are, however, of limited value. A reasonable estimate of the amount of herbicide usage changes that have occurred with GM HT crop technology, requires an assessment of what herbicides might reasonably be expected to be used in the absence of crop biotechnology on the three crops of corn, cotton and soybeans in the US (ie, if the entire crops were conventional). Applying usage rates for the current (remaining) conventional crops is one approach, as presented in 3. above. However, this invariably provides significant under estimates of what usage might reasonably be in the absence of crop biotechnology, because the conventional cropping dataset used to identify pesticide use relates to a relatively small share of total crop area. This has been the case for the US corn, cotton and soybean crops for many years. Thus in 2011, the conventional share (not using GM HT technology) of each crop was only 6%, 28% and 27% respectively for soybeans, corn and cotton[9], with the conventional share having been below 50% of the total since 1999 in respect of soybeans, since 2001 for cotton and since 2007 for corn. The reasons why this conventional cropping dataset is unrepresentative of the levels of herbicide use that might reasonably be expected in the absence of biotechnology include:

   - Whilst the degree of weed problems/damage vary by year, region and within region, farmers' who continue to farm conventionally may be those with relatively low levels of weed problems, and hence see little, if any economic benefit from using the GM HT traits targeted at minimal weed problems. Their herbicide usage levels therefore tend to be below the levels that would reasonably be expected on an average farm with more typical weed infestations;
   - Some of the farms continuing to use conventional seed generally use extensive, low intensity production methods (including organic) which feature, limited (below average) use of herbicides. The usage patterns of this sub-set of growers is therefore likely to understate usage for the majority of farmers if they all returned to farming without the use of GM HT technology;
   - Some of the farmers using GM HT traits have experienced improvements in weed control from using this technology relative to the conventional control methods previously used. If these farmers were to now switch back to using conventional techniques, it is likely that most would wish to maintain the levels of weed control delivered with use of the GM HT traits and therefore some would use higher levels of herbicide than they did in the pre GM HT crop days.

   In peer reviewed papers examining pesticide use changes arising from the adoption of GM crops undertaken by other analysts, this issue has been both discussed and addressed (compared to being ignored by Benbrook (2012)). For example, in Brookes and Barfoot (2012), the authors compare the recorded average herbicide active ingredient usage levels on both GM HT crops and conventional corn, cotton and soybean crops in the US derived from the Gfk Kynetec dataset before highlighting the above pitfalls of using only this data to assess the conventional alternative. Brookes & Barfoot (2012) address the problem of poor representativeness of the small conventional dataset by a) only using the average recorded values for herbicide usage on conventional crops for years when the conventional crop accounted for the majority of the total crop and b) in other years (from 1999 for soybeans, from 2001 for cotton and from 2007 for corn) applying estimates of the likely usage if the

[9] Source: USDA. Note the conventional share refers to not using GM HT technology, with some of the 'conventional crops' using crop biotechnology-traited seed providing GM insect resistance only. Also, the Gfk Kynetec dataset suggests that the proportion of the US corn and cotton crops not using GM HT technology in 2011 is smaller at 10% in both the corn and cotton crops

whole US crop was no longer using crop biotechnology, based on opinion from extension and industry advisors across the US as to what farmers might reasonably be expected to use in terms of weed control practices and usage levels of herbicide. In addition, the usage levels identified from this methodology were cross checked (and subject to adjustment) against historic average usage levels of key herbicide and insecticide active ingredients from the Gfk Kynetec dataset to minimise the scope for overstating likely usage levels on the conventional alternative.

Benbrook has, in earlier work (eg, Benbrook (2009), been critical of this approach and perceives it overstates the use on the conventional alternative, even though it is based on extension and industry advice and cross checked with historic recorded average usage levels. This contrasts significantly, with the approach taken by Benbrook (2012) which is based solely on personal interpretations and extrapolations of herbicide use for both GM HT and conventional crops. Benbrook (2012) does not present any information about typical weed control regimes that might reasonably be expected in conventional systems, if widely adopted by current GM HT crop users. Not surprisingly, Benbrook (2012) significantly under estimates usage of herbicides on the conventional crop alternatives. In some cases, estimates from Benbrook (2012) are significantly lower than the recorded levels of use on the existing small US conventional cropping areas of corn, cotton and soybeans. For example, in Benbrook (2012), the assumed average herbicide active use on conventional soybeans for the years 2007-2011 are respectively 0.93lb/acre, 0.82 lbs/acre, 0.86 lbs/acre, 0.72 lbs/acre and 0.96 lbs/acre (average 0.858 lbs/acre). This understated usage compared to the recorded herbicide usage on conventional soybeans in this period by an average of 23% (within a range of -10% to -35% on an annual basis: source: derived from Gfk Kynetec).

Overall, Benbrook (2012) overestimates herbicide use changes associated with the adoption of GM HT traits in the US by (mostly) significantly under estimating herbicide use on conventional crops (ie, what might reasonably be used in the absence of GM HT technology). This is the main reason why the conclusions of the Benbrook (2012) differ markedly from the more numerous analyses published in several peer reviewed journals. For example, a**pplying the Brookes and Barfoot (2012) methodology, allied to the Gfk Kynetec data set for the period 1996-2011[10] points to herbicide usage in the US having been 450 million lbs less over this period than it would otherwise have been if conventional technology alone had been used. This is equivalent to about an 8% decrease compared to the increase of over 9% claimed in the Benbrook (2012) paper.**

5. Based on the Gfk Kynetec source[11], the amount of herbicide active ingredient (ai) used per acre/hectare on the three crops during the period 1998-2011 period is as follows:
    - *Soybeans*: usage was fairly stable to the mid 2000s, but has increased in recent years;
    - *Corn:* average herbicide ai use fell by between 8% and 12% to the mid 2000s. Since then average use has increased to similar levels of use ten years ago;
    - *Cotton*: the average volume of herbicide ai used/ha on the US cotton crop remained fairly stable through the mid 2000s but has increased in recent years.

    Where the average amount of herbicide active ingredient use has increased in recent years, this is likely to have been influenced by factors such as the development of weed resistance (to glyphosate) and extension advice on how best to tackle this issue. It should, however, be noted that average herbicide active ingredient use on both conventional and GM HT crops

[10] GfK Kynetec dataset used for 1998-2011, with Benbrook (2012) assumptions for 1996 and 1997 applied
[11] These trends are consistent with those identified using USDA data

has been increasing in recent years, highlighting that weed resistance issues are not unique to GM HT production systems. This issue is discussed further in 9 below.

6. Based on Gfk Kynetec data[12], the amount of insecticide active ingredient (ai) used per acre/hectare on corn and cotton during the period 1998-2011 is as follows:
    - *Corn:* average insecticide ai use fell by about 90% (in terms of active ingredient usage per acre/ha);
    - *Cotton*: the average volume of insecticide ai used/ha of the US cotton crop fell by about 35% to 40%.

7. In the third paragraph of the 'Results and discussion' section of Benbrook (2012) passing reference is made to glyphosate being a more environmentally benign active ingredient than some of the herbicides it replaced (and commonly used on conventional crops of corn, cotton and soybeans) though this is 'offset' by a subsequent spurious references to glyphosate residue levels found in bread samples in the UK. Benbrook (2012) provides no balanced discussion of the issues, and more specifically fails to discuss:
    - The favourable toxicity profile of glyphosate relative to the herbicides it replaced;
    - Why assessing the health and environmental impacts of changes in herbicide use with GM crops based solely on changes in herbicide active ingredient use is widely accepted as a crude and poor measure of impact (see 8. below).

8. There exist alternative (and better) measures that have been used by a number of authors of peer reviewed papers to assess the environmental impact of herbicide use change with GM HT crops rather than simply looking at changes in the volume of active ingredient applied to crops. Benbrook (2012) includes no such discussion of these issues or of alternative indicators. In particular, there are a number of peer reviewed papers that utilise the Environmental Impact Quotient (EIQ) developed at Cornell University by Kovach et al (1992) and updated annually. This effectively integrates the various environmental impacts of individual pesticides into a single 'field value per hectare'. The EIQ value is multiplied by the amount of pesticide active ingredient (ai) used per hectare to produce a field EIQ value. For example, the EIQ rating for glyphosate is 15.33. By using this rating multiplied by the amount of glyphosate used per hectare (eg, a hypothetical example of 1.1 kg applied per ha), the field EIQ value for glyphosate would be equivalent to 16.86/ha. The EIQ indicator used is therefore a comparison of the field EIQ/ha for conventional versus GM crop production systems, with the total environmental impact or load of each system, a direct function of respective field EIQ/ha values and the area planted to each type of production (biotech versus conventional). The use of environmental indicators is commonly used by researchers and the EIQ indicator has been, for example, cited by Brimner et al (2004) in a study comparing the environmental impacts of GM and conventional canola and by Kleiter et al (2005). The EIQ indicator provides an improved assessment of the impact of GM crops on the environment when compared to only examining changes in volume of active ingredient applied, because it draws on some of the key toxicity and environmental exposure data related to individual products, as applicable to impacts on farm workers, consumers and ecology.

[12] These trends are consistent with those identified using USDA data

9. Benbrook (2012) devotes significant space to discussing the issue of weeds that are resistant to glyphosate and portrays an image that the adoption of GM HT crops has resulted in the widespread development of weeds resistant to glyphosate that are very difficult to control and require the use of additional mixtures of other herbicides.

   This portrayal is an exaggeration of reality; there are currently 24 weeds recognized as exhibiting resistance to glyphosate worldwide, of which several are not associated with glyphosate tolerant crops (www.weedscience.org). For example, there are currently 13 weeds recognized in the US as exhibiting resistance to glyphosate, of which two are not associated with glyphosate tolerant crops.

   Where GM HT crops have been widely grown, some incidence of weed resistance to glyphosate has occurred. This has been attributed to how glyphosate was used; because of its broad-spectrum post-emergence activity, it was often used as the sole method of weed control. This approach to weed control put tremendous selection pressure on the product and as a result contributed to the evolution of weed populations predominated by resistant individual weeds. In addition, it should be noted that the adoption of GM HT technology has played a major role in facilitating the adoption of no and reduced tillage production techniques in North and South America. This has also probably contributed to the emergence of weeds resistant to herbicides like glyphosate and to weed shifts towards those weed species that are not well controlled by glyphosate. A few of the glyphosate resistant species, such as marestail (*Conyza canadensis*) and palmer pigweed (*Amaranthus palmeri*) are now reasonably widespread in the US. In Benbrook (2012), there is discussion about problems with weed resistance to glyphosate, with various estimates of the affected area (within a range of 10%-50% of the total area annually devoted to corn, cotton and soybeans).

   Benbrook (2012) fails to place this resistance development in context. All weeds have the ability to develop resistance to all herbicides and there are hundreds of resistant weed species confirmed in the International Survey of Herbicide Resistant Weeds (www.weedscience.org), as cited above and reports of herbicide resistant weeds pre-date the use of GM HT crops by decades. Where farmers are faced with the existence of weeds resistant to glyphosate, there is a recognized need to adopt reactive weed management strategies incorporating the use of herbicides with alternative modes of action among other integrated weed management practices (ie, the same way as control of other non-glyphosate herbicide resistant weeds).

   In recent years, there has also been a growing consensus among weed scientists of a need for changes in the weed management programmes in GM HT crops, because of the evolution of these weeds towards populations that are resistant to glyphosate. Growers of GM HT crops are increasingly being advised to be more proactive and include other herbicides (with different and complementary modes of action) in combination with glyphosate in their integrated weed management systems, even where instances of weed resistance to glyphosate have not been found.

   This proactive, diversified approach to weed management is therefore the principal strategy for avoiding the emergence of herbicide resistant weeds in GM HT crops. A proactive weed

management programme also generally requires less herbicide, has a better environmental profile and is more economical than a reactive weed management programme.

At the macro level, the adoption of both reactive and proactive weed management programmes in GM HT crops has already begun to influence the mix, total amount and overall environmental profile of herbicides applied to GM HT soybeans, cotton, corn and canola. This is shown in the evidence relating to changes in herbicide use, as reported in the annual farm level surveys conducted by Gfk Kynetec, where the mix of herbicides on GM HT crops has increased, and in the analysis of authors such as Brookes and Barfoot (eg, 2012). For example, in the US GM HT soybean crop in 2010, just over a third of the crop received an additional herbicide treatment of one of the following active ingredients[13] 2,4-D, chlorimuron, clethodim and flumioxazin. This compares with 13% of the GM HT soybean crop receiving a treatment of one of these four herbicide active ingredients in 2006. As a result, the average amount of herbicide active ingredient applied to GM HT soybeans in the US (per hectare) increased by about a third over the previous five year period (the associated EIQ value has increased by about 27%). This compared with the average amount of herbicide active ingredient applied to the conventional (non GM) soybean alternative which increased by 15% over the same period (the associated EIQ value for conventional soybeans increased by 27%). The increase in the use of herbicides on conventional soybeans in the US can also be partly attributed to the ongoing development of weed resistance to non-glyphosate herbicides commonly used and highlights that the development of weed resistance to herbicides is a problem faced by all farmers, regardless of production method. In addition, it is interesting to note that in the US cotton crop, whilst the average amount of herbicide active ingredient used has increased over the last five years, during the last two seasons, average use of glyphosate has fallen, being replaced with additional use of other herbicides. This suggests that US cotton farmers are increasingly adopting current/recent recommended practices for managing weed resistance (to glyphosate).

Relative to the conventional alternative, however, the overall environmental profile of herbicides used with GM HT crops and the economic impact of the GM HT crops continues to offer important advantages[14]. If the GM HT technology was no longer delivering such net economic benefits (as implied by Benbrook (2012 pages 7-8), US farmers would have significantly reduced their adoption of this technology in favour of conventional alternatives. The fact that GM HT crop adoption levels in the US have not fallen in recent years suggests that US farmers must be deriving important economic benefits from using the technology; *if they didn't why would they use it*[15]*?*

[13] The four most used herbicide active ingredients used on soybeans after glyphosate (source: derived from GfK Kynetec)

[14] Also, many of the herbicides used in conventional production systems had significant resistance issues themselves in the mid 1990s. This was, for example, one of the reasons why glyphosate tolerant soybeans were rapidly adopted, as glyphosate provided good control of these weeds

[15] The continued delivery of net economic benefits from using GM HT technology, even after adopting recommended practices for managing weed resistance issues has been confirmed by other analysts (eg, Hurley T et al (2009))

10. Claims are made in Benbrook (2012; page 7) that *'if 2,4-D and dicamba (herbicide) tolerant corn and soybeans are fully deregulated, there will be growing reliance on older, higher-risk herbicides for the management of glyphosate-resistant weeds' and 'herbicide tolerant 2,4-D corn could reach 55% of corn hectares by 2019, resulting in a 30 fold increase in usage from 2010 levels'* The use of 2,4-D and dicamba in GM HT crops (corn, soybeans and cotton) will add to overall herbicide use but will also replace the use of some currently used herbicides. For example, 2,4-D and dicamba will replaces certain post-emergence active herbicides (for example MSMA and paraquat in cotton) because of easier application and better performance on key weeds species. These herbicides also replace certain pre-emergence residual herbicides because there is decreased need for rainfall to activate them, they lead to reduced concern about carryover (of herbicides into the soil where follow on crops are planted) and they replace certain post-emergence active herbicides (eg, those in the ALS grouping) for which there are significant weed resistance issues (eg, there are over 100 weeds that exhibit resistance to the ALS group of herbicides). In addition, similar to the analysis of past trends, the claims made in Benbrook (2012) about future herbicide use trends are based on his own assumptions of increased application numbers and rates, and incorporate assumed increases in planted acreage that are not supported by official acreage projections.

11. *Public health concerns. In Benbrook (2012: page 8) claims are made about a 'heightened risk of public health impacts can be expected in the wake of more intensive herbicide use' and 'the likely approval and use of herbicide resistant crops engineered to survive application of multiple herbicides adds tricky new dimensions to herbicide risk assessment. Applications later in the growing season will be more likely to lead to residues in silage and other fodder crops'*
    These claims are speculative:

    - Under both current and future expected use of glyphosate with GM crops, glyphosate does not pose any health risk to humans (see for example, Williams et al (2000);
    - Whilst some new GM HT traits likely to be available for commercial use in the US in the next few years are associated with herbicides that can be applied post-emergence, this does not mean that they will necessarily be used late in the crop growth cycle. The optimum time for weed control is in the early crop growth stages and this is when the majority of all herbicides are applied, whether or not they are directly associated with GM HT-traited varieties or not. In addition, all approved applications of herbicide with GM HT crops, whether 'late' or 'early' are required to be evaluated and approved by the appropriate regulatory agencies.

12. Benbrook (2012) makes a number of claims relating to negative environmental impacts linked to GM HT technology. These include the following:
    - *Claim that glyphosate impairs soil microbial communities that can increase plant vulnerability to pathogens.* Many studies have examined the potential for disease in glyphosate-resistant crops, including soybeans, corn, cotton, sugar beet, and wheat. There are three factors within the glyphosate-resistant cropping system that could potentially affect the susceptibility of the crop to disease. These factors are a) the baseline disease resistance or susceptibility of different genotypic varieties of a crop; b) the presence of the glyphosate resistance gene; and c) treatment with glyphosate. Duke et al (2012) concluded that most

of the available data supports the view that it is the underlying resistance or susceptibility of the host plant, and not the presence of the glyphosate resistance gene or treatment with glyphosate that is the major contributor to susceptibility to disease. Studies on the effects of glyphosate on the microbial populations in soil and the rhizosphere, and on overall microbial community structures, have shown variable results, with many concluding that glyphosate has little effect on microbial populations;

- *Claim that glyphosate reduces the availability of micronutrients*. Benbrook (2012) cites two references that claim glyphosate reduces micronutrient concentrations in plants. Cakmak et al (2009: reference 38), incorrectly listed as a pathogen reference, describes the effects of glyphosate on non-glyphosate resistant soybeans. This is not relevant to the discussion of glyphosate effects on herbicide-resistant crops, as glyphosate is known to translocate to and damage roots of susceptible plants, resulting in a side effect of reduced nutrient uptake. The work described in the second reference (Zobiole et al, (2009) reference 39) was conducted only in the greenhouse. Duke et al (2012) conducted a comprehensive review of available studies on the effects of glyphosate on micronutrient availability and concluded that glyphosate does not affect micronutrients in glyphosate tolerant crops. In addition, Harris et al (2012) has shown that glyphosate is not an effective chelator of micronutrients in plants, and therefore would not be expected to have a significant impact on the availability of micronutrients in plants;
- *Claim that glyphosate leads to a reduction in water use efficiency:* Benbrook (2012) cites one study on the effect of glyphosate on water use efficiency (reference 42, Zobiole et al (2009). This study was undertaken in a greenhouse (soybeans grown in a hydroponic solution). The study did not examine field planting of soybeans;
- *A claim that glyphosate-tolerant crops results in a reduction in nitrogen fixation:* Benbrook (2012) cites two studies that have documented reductions in nitrogen fixation in herbicide-resistant soybean fields. One of the studies (reference 43, Zobiole et al (2010)) was, as indicated above, not a field study, having only been conducted in a greenhouse. The other study (reference 44, King et al (2001) included greenhouse, growth chamber and field experiments; reductions in N content in the field experiments were seen only in a water-limited environment, and that the effect of glyphosate on nitrogen fixation was dependent on the genetic background of the crop. In addition, the authors stated that glyphosate is unlikely to have any long-term effects on nitrogen fixation or other processes affecting soybean yield in a high-yielding environment. In addition, Duke et al (2012) reviewed the literature on nitrogen fixation, and concluded that the effect was dependent on the soybean cultivar;
- *A claim that 'heavy use of glyphosate can reduce earthworm viability'* [reference 41, Casabé N et al (2007). This is not supported in most literature, where earthworms are predicted to be at minimal risk from the use of glyphosate (see for example, Giesy J et al (2000) and Edwards C and Bohlen P (1996). In addition, it should be noted that the Casabé N et al (2007) work was based on using glyphosate concentrations that were substantially above actual usage. The lowest concentrations used by Casabé N et al (2007) were equivalent to an application rate of 100 lb/acre of glyphosate. This compares with the typical application rates in the field of about 1-1.5 lb/acre;
- *A claim that 'landscapes dominated by herbicide-resistant crops support fewer insect and bird species (eg, a study in the American Midwest reported a 58% decline in milkweed and an 81%*

drop in monarch butterflies from 1999 to 2010' [reference 40 Pleasants J and Oberhauser (2012) There is no data that support the statement that *'herbicide-resistant crops support fewer insect and bird species'*. Several studies have examined changes in the number of Monarch butterflies in the US Mid West (including the one cited by Benbrook (2012) above) and factors affecting butterfly numbers. Pleasants and Oberhauser (2012) concluded that increased use of glyphosate has been an important factor responsible for the reduction in milkweeds (that Monarchs feed on). The size of the migrating Monarch population is, however, known to be affected by environmental factors (eg, drought or frost on the migration route from Mexico to Canada, or reduction in over wintering habitats, as well as predation, insecticide use and motor vehicles). Overall, there are many factors that potentially influence Monarch butterfly populations, of which the use of glyphosate is one. The current state of knowledge on factors affecting Monarch butterfly populations is probably best summed up by Harzler (2010) *'estimates of monarch wintering populations in Mexico over the time frame of the common milkweed surveys do not indicate a decline in butterflies that parallels that of common milkweed (www.monarchwatch.org). Rather, fluctuations in monarchs were reported to correlate with climatic events that influenced survival and reproduction of the monarch. Thus, the long-term impact of declining common milkweed populations in Iowa on monarchs is difficult to assess'*.

13. Benbrook (2012) also makes a claim that *the nature of the Bt-transgene technology in GM IR corn and cotton should be 'counted' as insecticides applied* and that '*Bt Cry proteins poses more significant risks to animals and humans ingesting Bt crops than applications of Bt insecticides via liquid sprays'* Firstly, Bt proteins are not considered to pose the same health risks as applied chemical insecticides because, following ingestion, proteins are typically digested whereas chemicals are not and can be absorbed systemically. Secondly, Bt proteins are not toxic when administered to mammals and there is a long history of safe Bt use (more than 50 years) in agriculture either as a spray or via crop biotechnology[16]. Furthermore, Benbrook (2012) produced no evidence from reputable journals to support his claim.

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[16] See for example, OECD (2007), WHO IPCS (1999) and McClintock J et al (1995)

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