GM SOY
Sustainable? Responsible?

A summary of scientific evidence showing that genetically modified (GM) soy and the glyphosate herbicide it is engineered to tolerate are unsustainable from the point of view of farming, the environment, rural communities, animal and human health, and economies

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September 2010

GM_FULL_ENG_v10

Published by:

GLS Bank
das macht Sinn

GLS Gemeinschaftsbank eG, Christstr. 9, 44789 Bochum, Germany. www.gls.de

ARGE Gentechnik-frei (Arbeitsgemeinschaft für Gentechnik-frei erzeugte Lebensmittel), Schottenfeldgasse 20, 1070 Vienna, Austria. www.gentechnikfrei.at

Supported by:

GLS Treuhand e.V.
Bochum, Germany
www.gls-treuhand.de

About the authors and publishers of GM Soy: Sustainable? Responsible?

This report was compiled by an international coalition of scientists who hold the view that the complete body of evidence on GM soy and glyphosate herbicide should be made accessible to everyone – government, industry, the media, and the public. The scientists and their contact details are as follows:

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Note: The views expressed in the report, GM Soy: Sustainable? Responsible? are those of the individuals who co-authored the report. There is no implication or claim that they reflect or represent the views of the institutions with which these individuals are or have been affiliated.

The publishers of this report were inspired by the scientists' work on this issue to support its release to the public. The full report and summary of key findings can be downloaded from the publishers' websites:
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EXECUTIVE SUMMARY

Awareness is growing that many modern agricultural practices are unsustainable and that alternative ways of ensuring food security must be found. In recent years, various bodies have entered the sustainability debate by attempting to define the production of genetically modified Roundup Ready® (GM RR) soy as sustainable and responsible.

These include ISAAA, a GM industry-supported group; the research organization, Plant Research International at Wageningen University, the Netherlands, which has issued a paper presenting the arguments for the sustainability of GM RR soy; and the Round Table on Responsible Soy (RTRS), a multi-stakeholder forum with a membership including NGOs such as WWF and Solidaridad and multinational companies such as ADM, Bunge, Cargill, Monsanto, Syngenta, Shell, and BP.

This report assesses the scientific and other documented evidence on GM RR soy and asks whether it can be defined as sustainable and responsible.

GM RR soy is genetically modified to tolerate the herbicide Roundup®, based on the chemical glyphosate. The transgenic modification allows the field to be sprayed with glyphosate, killing all plant life except the crop. GM RR soy was first commercialized in the United States in 1996. Today, GM RR varieties dominate soy production in North America and Argentina and are widely cultivated in Brazil, Paraguay, Uruguay and Bolivia.

Glyphosate is an essential element in the GM RR soy farming system. Because of this, the rapid expansion of GM RR soy production has led to large increases in the use of the herbicide.

The industry claims that glyphosate is safe for people and breaks down rapidly and harmlessly in the environment. But a large and growing body of scientific research challenges these claims, revealing serious health and environmental impacts. The adjuvants (added ingredients) in Roundup increase its toxicity. Harmful effects from glyphosate and Roundup are seen at lower levels than those used in agricultural spraying, corresponding to levels found in the environment.

The widespread spraying of glyphosate on GM RR soy, often carried out from the air, has been linked in reports and scientific research studies to severe health problems in villagers and farmers. A recently published study links glyphosate exposure to birth defects. In some regions around the world, including a GM RR soy-producing region of Argentina, courts have banned or restricted such spraying.

For farmers, GM RR soy has not lived up to industry claims. Studies show that GM RR soy consistently delivers low yields. Glyphosate applications to the crop have been shown in studies to interfere with nutrient uptake, to increase pests and diseases, and to reduce vigour and yield.

The most serious problem for farmers who grow GM RR soy is the explosion of glyphosate-resistant weeds, or "superweeds". Glyphosate-resistant weeds have forced farmers onto a chemical treadmill of using more and increasingly toxic herbicides. In some cases, no amount of herbicide has allowed farmers to gain control of weeds and farmland has had to be abandoned.

The no-till farming model that is promoted as part of the GM RR soy technology package avoids ploughing with the aim of conserving soil. Seed is planted directly into the soil and weeds are controlled with glyphosate applications rather than mechanical methods.

Claims of environmental benefits from the no-till/GM RR soy model have been found to be misleading. The system has added to the glyphosate-resistant weed problem and has been shown to increase the environmental impact of soy production when the herbicides used to control weeds are taken into account. Also, the production of GM RR soy has been found to require more energy than the production of conventional soy.

There are also serious safety questions over the transgenic modifications introduced into GM RR soy. Contrary to claims by the GM industry and its supporters, the US Food and Drug Administration FDA has never approved any GM food as safe. Instead, it de-regulated GM foods in the early 1990s, ruling that they are "substantially equivalent" to non-GM foods and do not need any special safety testing. The ruling was widely recognized as a political decision with no basis in science. In fact, "substantial equivalence" has never been scientifically or legally defined.

Since then, a number of studies have found health hazards and toxic effects associated with GM RR soy. These include cellular changes in organs, more acute signs of ageing in the liver, enzyme function disturbances, and changes in the reproductive organs. While most of these studies were conducted on experimental animals, the findings suggest that GM RR soy may also impact human health. This possibility has not been properly investigated.

Proponents of GM RR soy often justify its rapid expansion on economic grounds. They argue that the crop increases prosperity for farmers, rural communities, and the economy, so it is irresponsible to ask for proper risk assessment.

However, when on-farm economic impacts of growing GM crops are measured, the results are often disappointing. For example, a study for the European Commission found no economic benefit to US farmers from growing GM RR soy over non-GM soy. The most frequently cited benefit for farmers of growing GM RR soy, simplified weed control, is fast unravelling due to the spread of glyphosate-resistant weeds.

Argentina is widely cited as an example of the success of the GM RR soy farming model. But RR soy production in the country has been linked to serious socioeconomic problems, including displacement of farming populations to cities, concentration of agricultural production into the hands of a small number of operators, loss of food security, poor nutrition, and increased poverty and unemployment.

There are concerns too over the near-monopolistic control of the seed supply in many countries by GM companies. In the United States, this has led to large increases in GM RR soy seed costs – as much as 230 per cent in 2009 over 2000 levels – undermining the economic sustainability of soy farming.

High seed costs, glyphosate-resistant weed problems, and lucrative premiums for non-GM soy harvests are prompting farmers in North and South America to move away from GM RR soy. The industry strategy for countering this trend has been to gain control of the seed supply and restrict the availability of non-GM soy seed to farmers.

GM crops threaten export markets because of consumer rejection in many countries. The discovery of GM contamination of food and feed supplies has repeatedly led to large recalls and major market losses. Ongoing measures to avoid GM contamination are costing the food and agriculture industry millions.

In summary, most of the benefits claimed for GM RR soy are either short-lived (such as simplified and less toxic weed control) or illusory (such as increased yield and less toxic weed control). Many of the claimed benefits of GM RR soy have not been realized, while many of the anticipated problems (such as glyphosate-resistant weeds, disruptions of soil ecology, and negative effects on crops), have been confirmed.

The weight of evidence from scientific studies, documented reports, and on-farm monitoring shows that both GM RR soy and the glyphosate herbicide it is engineered to tolerate are destructive to agricultural systems, farm communities, ecosystems, and animal and human health. The conclusion is that GM RR soy cannot be termed sustainable or responsible.

INTRODUCTION

Concern has grown over the sustainability of modern agriculture is no longer the province of fringe organizations, but has gone mainstream. A broad consensus has emerged that in the area of agriculture and food production, “business as usual” is no longer an option.

In 2008 the World Bank and four United Nations agencies completed a four-year study on the future of farming. Conducted by over 400 scientists and development experts from 80 countries and endorsed by 58 governments, the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) report concluded that expensive, short-term technical fixes – including genetically modified (GM) crops – are unlikely to address the complex challenges that farmers face.

Instead, IAASTD recommended tackling the underlying causes of poverty. IAASTD identified priorities for future agricultural research as “agroecological” farming practices. It called for more cooperation between farmers and interdisciplinary teams of scientists to build culturally and ecologically appropriate food production systems.[1]

Other organizations have reached similar conclusions. La Via Campesina, the international peasant farmers’ movement, brings together 148 organisations in 69 countries. The organization supports low-input and environmentally sustainable farming and opposes high-input and GM crop-based systems.[2] Consumers International, with over 220 member organizations in 15 countries, has published reports warning consumers and food producers about the risks of GM crops and foods[3] and calling for ecologically and socially responsible food production.[4]

Running counter to this trend, some bodies have attempted to shift the definition of sustainable agriculture to include the cultivation of GM crops in general, and GM Roundup Ready® (GM RR) soy in particular. These include:

- Aapresid (Argentine No-till Farmers Association)[5]
- ISAAA, a GM industry-supported group[6]
- National Biosafety Association–ANBio, Brazil[7]
- Plant Research International at Wageningen University, the Netherlands, which has issued a paper presenting the arguments for the sustainability of GM RR soy[8]
- The Round Table on Responsible Soy (RTRS),[9] a multi-stakeholder forum with a membership including NGOs such as WWF and Solidaridad and multinational companies such as ADM, Bunge, Cargill, Monsanto, Syngenta, Shell, and BP
- The Soja Plus programme[10] in Brazil, sponsored by ABIOVE (Oilseed Industries Brazilian Association), ANEC (National Exports Grain Association), APROSOJA (Soybean Farmers Association) and ARES (Institute for Responsible Agribusiness).

With at least two radically different definitions of sustainability vying for acceptance, it is necessary to take a closer look at GM RR soy in order to decide whether its cultivation can be considered sustainable and responsible.

About GM RR soy

GM RR soy was developed by Monsanto and was first commercialized in the United States in 1996. The crop is genetically modified to tolerate Monsanto’s best-selling herbicide Roundup, based on the chemical glyphosate. Monsanto patented the glyphosate molecule in the

1970s and marketed Roundup from 1976. It retained exclusive rights in the US until its US patent expired in September, 2000. Since then, other companies have also manufactured the herbicide.

The RR gene allows the growing crop to be sprayed with glyphosate, killing weeds and other plants but allowing the crop to grow on.

The apparent simplicity of the GM RR soy system has led to high take-up by farmers. In 2009 in the United States and Argentina, over 90 per cent of the soy crop was the GM RR variety.[11] GM RR soy dominates production in Argentina, Paraguay, and parts of Brazil, and is moving into Bolivia and Uruguay.

Over 15 years of commercial production, a large body of evidence on the impacts of GM RR soy has emerged in the form of scientific research, on-farm monitoring, and expert reports. Areas of study include the health and environmental effects of GM RR soy and the glyphosate herbicide that accompanies it, agronomic performance, and economic impacts to farmers and markets. Additional evidence has accumulated on the no-till farming model that is promoted as part of the GM RR soy package.

This report presents and assesses the evidence that has accumulated on GM RR soy and its cultivation in an attempt to answer the question, "Can GM RR soy be defined as responsible or sustainable?"

The North American experience

While this report focuses on claims of sustainability for GM RR soy cultivation globally, much of the data has been gathered in North America. The North American experience of growing GM crops is relevant, as the United States has grown GM crops over a larger area and for a longer time than any other country.

The technology has proven attractive to American growers with large farms and fields and a high degree of mechanization, mainly because of the simplified weed control system.[12] The United States also has a favourable infrastructure for GM monoculture and government subsidies for growing GM crops, implemented soon after the introduction of GM RR soy in 1996.[13] In 2001 the UK farm journal Farmers Weekly reported that 70 per cent of soybean value came from the US government.[14 15]

For all these reasons, GM crops in North America should be an unqualified success story. Yet this is not the case. Problems have emerged with GM crops in the US – and South America is following the same trajectory. Also, public health and socioeconomic problems have appeared in South America as a result of GM RR soy expansion and accompanying glyphosate use.

TOXIC EFFECTS OF GLYPHOSATE AND ROUNDUP

More than 95 per cent of GM soy (and 75 per cent of other GM crops) is engineered to tolerate glyphosate-based herbicide, the most common formulation of which is Roundup. Monsanto patented the glyphosate molecule in the 1970s and first commercialized Roundup in 1976.[16] Since Monsanto's US patent expired in 2000, other companies have been able to sell their own brands of glyphosate herbicide[17] and Monsanto has become increasingly reliant on its GM glyphosate-tolerant seeds business for revenue.

Glyphosate works as a broad-spectrum, non-selective weedkiller by inhibiting an enzyme in plants that does not exist in human and animal cells. On that basis, the manufacturers claim that glyphosate is safe and nontoxic for humans and animals. But a growing body of research shows that these claims are misleading. In addition, the added ingredients (adjuvants) in Roundup have been found to pose hazards and in some cases to increase the toxicity of glyphosate.

Glyphosate and Roundup formulations have been found in studies to be endocrine disruptors (substances that interfere with the functioning of hormones) and to be toxic and lethal to human cells. In animals, they disturb hormone and enzyme function, impede development, and cause birth defects.

Findings include:

- A study on human cells found that all four Roundup formulations tested caused total cell death within 24 hours. These effects were found at dilution levels far below those recommended for agricultural use and corresponding to low levels of residues found in food or feed. The adjuvants in Roundup increase the toxicity of glyphosate because they enable the herbicide to penetrate human cells more readily.[18]
- Glyphosate-based herbicides are endocrine disruptors. In human cells, glyphosate-based herbicides prevented the action of androgens, the masculinising hormones, at very low levels – up to 800 times lower than glyphosate residue levels allowed in some GM crops used for animal feed in the United States. DNA damage was found in human cells treated with glyphosate-based herbicides at these levels. Glyphosate-based herbicides also disrupt the action and formation of estrogens, the feminizing hormones.[19]
- Glyphosate is toxic to human placental cells in concentrations lower than those found with agricultural use. Glyphosate acts as an endocrine disruptor, inhibiting an enzyme that converts androgens into estrogens. This effect increases in the presence of Roundup adjuvants.[20]
- Glyphosate and the formulated product Roundup Bioforce damage human embryonic cells and placental cells, in concentrations well below those recommended

for agricultural use. The study's authors conclude that Roundup may interfere with human reproduction and embryonic development. Moreover, the toxic and hormonal effects of the formulations appear to be underestimated.[21]

- The adjuvants in Roundup make the cell membrane more permeable to glyphosate and increase its activity in the cell.[22 23]
- Roundup is toxic and lethal to amphibians. A study based in a natural setting found that Roundup application at the rate recommended by the manufacturer completely eliminated two species of tadpoles and nearly exterminated a third species, resulting in a 70 per cent decline in the species richness of tadpoles. The species richness of aquatic communities was reduced by 22 per cent with Roundup, a greater effect than was found with the insecticide Sevin or the herbicide 2,4-D. Contrary to common belief, the presence of soil does not mitigate the chemical's effects.[24] Monsanto objected to the study on the grounds that the application rates were unrealistically high, that the concentrations tested would not occur in water in real-life conditions, and that the Roundup formulation tested is not intended for application over water.[25] The researcher, Dr Rick Relyea, replied that the application rates corresponded to the manufacturer's data. He added that the concentrations in water were at the higher end of levels to be expected but were realistic, according to Monsanto's own data.[26] He pointed out that the Roundup formulation tested can and does get into aquatic habitats during aerial spraying.[27] Moreover, Relyea conducted subsequent experiments using only one-third as much Roundup, well within the concentrations to be expected in the environment. This lower concentration still caused 40 per cent amphibian mortality.[28]
- Experiments on sea urchin embryos show that glyphosate-based herbicides and glyphosate's main metabolite (environmental breakdown product), AMPA, alter cell cycle checkpoints by interfering with the physiological DNA repair machinery. Such cell cycle dysfunction is seen from the first cell division in the sea urchin embryos.[29 30 31 32] The failure of cell cycle checkpoints is known to lead to genomic instability and the possible development of human cancers. Reinforcing these findings, studies on glyphosate and AMPA suggest that the irreversible damage that they cause to DNA may increase the risk of cancer.[33 34]
- Glyphosate herbicide alters hormone levels in female catfish and decreases egg viability. The results show that the presence of glyphosate in water was harmful to catfish reproduction.[35]
- Roundup residues interfere with multiple metabolic pathways of cells at low concentrations.[36]
- Glyphosate affects the levels and functioning of multiple liver and intestinal enzymes in rats.[37]
- Glyphosate is toxic to female rats and causes skeletal malformations in their foetuses.[38]
- AMPA, the major environmental breakdown product of glyphosate, causes DNA damage in cells.[39]

These findings show that glyphosate and Roundup are toxic to many organisms and to human cells.

Study confirms glyphosate's link with birth defects

In 2009 the Argentine government scientist Professor Andrés Carrasco announced his research team's findings that glyphosate-based herbicide causes malformations in frog embryos, in doses much lower than those used in agricultural spraying. Also, frog and chicken embryos treated with glyphosate herbicide developed similar malformations to those seen in the offspring of humans exposed to such herbicides.[40]

Effects repeatedly found included reduced head size, genetic alterations in the central nervous system, increase in the death of cells that help form the skull, and deformed cartilage. The authors concluded that the results raise "concerns about the clinical findings from human offspring in populations exposed to GBH in agricultural fields".

Carrasco said, "The findings in the lab are compatible with malformations observed in humans exposed to glyphosate during pregnancy." He added that his findings have serious implications for people because the experimental animals share similar developmental mechanisms with humans.[41]

Significantly, Carrasco found malformations in frog and chicken embryos injected with 2.03 mg/kg glyphosate. The maximum residue limit allowed in soy in the EU is 20 mg/kg, 10 times higher.[42] Soybeans have been found to contain glyphosate residues at levels up to 17mg/kg.[43]

Carrasco conducted further tests that show that glyphosate itself was responsible for the malformations, rather than the adjuvants in Roundup.

The authors concluded that both glyphosate-based herbicide and glyphosate alone interfered with key molecular mechanisms regulating early development in frog and chicken embryos, leading to malformations.

Carrasco is professor and director of the laboratory of molecular embryology at the University of Buenos Aires Medical School and lead researcher of the National Council of Scientific and Technical Research (CONICET). He was led to research the effects of glyphosate on frogs by reports of effects on humans of glyphosate-based herbicide spraying in agricultural areas. These included an epidemiological study in Paraguay that found that women who were exposed during pregnancy to herbicides delivered offspring with birth defects, particularly microcephaly (small head), anencephaly (absence of part of the brain and head), and malformations of the skull.[44]

Carrasco's team also noted reports from Argentina of an increase in birth defects and spontaneous abortions in areas of "GMO-based agriculture". They noted, "These findings were concentrated in families living a few meters from where the herbicides are regularly sprayed". They added that this information is worrying because of the high risk of environmentally induced disruptions in human development during the first eight weeks of pregnancy. A previous study had shown that glyphosate can pass through the human placenta and into the foetal compartment.[45]

The authors commented that most of the safety data on glyphosate-based herbicides and GM RR soy were provided by industry. The problem with this approach is shown by research on endocrine disrupting effects of chemicals. Independent studies have found ill effects from low doses, while industry studies have found no effect. Because of this, the authors write, a body of independent research is needed to evaluate the effects of agrochemicals on human health.

The researchers criticized Argentina's over-reliance on glyphosate caused by the expansion of GM RR soy, which in 2009 covered 19 million hectares.[46] [47] They noted that 200 million litres of glyphosate-based herbicide are used in the country to produce 50 million tons of soybeans per year. They concluded, "The intensive and extensive agricultural models based on the GMO technological package are currently applied without critical evaluation, rigorous regulations, and adequate information about the impact of sublethal doses on human health and the environment."

The authors condemned the fact that even the weight of scientific evidence and clinical observations are not enough to activate the precautionary principle and trigger investigation of the "depth of the impact on human health produced by herbicides in GMO-based agriculture".

Commenting on his team's findings in an interview with the Financial Times, Carrasco said that people living in soy-producing areas of Argentina began reporting problems in 2002, two years after the first big harvests of GM RR soy. He said, "I suspect the toxicity classification of glyphosate is too low ... in some cases this can be a powerful poison."[48]

Proposed ban on glyphosate and court ruling

After the initial release of Carrasco's research findings, a group of environmental lawyers petitioned the Supreme Court of Argentina to ban the sale and use of glyphosate. But Guillermo Cal, executive director of CASAFE (Argentina's crop protection trade association), said a ban would mean "we couldn't do agriculture in Argentina".[49]

No such national ban was implemented. But in March 2010, just months after the release of Carrasco's findings, a court in Santa Fe province in Argentina upheld a decision blocking farmers from spraying agrochemicals near populated areas. The court found that farmers "have been indiscriminately using agrochemicals such as glyphosate, applied in open violation of existing laws [causing] severe damage to the environment and to the health and quality of life of the residents". While the decision is limited to the area around San Jorge, other courts are likely to follow suit if residents seek similar court action.[50]

Chaco government report

In April 2010, as a result of pressure from residents and doctors, a commission opened by the provincial government of Chaco, Argentina completed a report analyzing health statistics in the town of La Leonesa and other areas where soy and rice crops are heavily sprayed.[51] The commission reported that the childhood cancer rate tripled in La Leonesa from 2000 to 2009. The rate of birth defects increased nearly fourfold over the entire state of Chaco.

This dramatic increase of diseases occurred in just a decade, coinciding with the expansion of the agricultural frontier into the province and the corresponding rise in agrochemical use.

The report mentioned glyphosate and several other agrochemicals as causing problems. It noted that complaints from sprayed residents centred on "transgenic crops, which require aerial and ground spraying (dusting) with agrochemicals". The report recommended that "precautionary measures" should be taken until an environmental impact assessment can be carried out.

A member of the commission that prepared the study, who asked not to be identified due to the "tremendous pressures" they were under, said, "all those who signed the report are very experienced in the subject under study, but rice and soy planters are strongly pressuring the government. We don't know how this will end, as there are many interests involved."[52]

Community prevented from hearing glyphosate researcher

There is intense pressure on researchers and residents in Argentina not to speak out about the dangers of glyphosate and other agrochemicals. In August 2010 Amnesty International reported that an organized mob violently attacked community activists, residents, and public officials who gathered to hear a talk by Professor Andrés Carrasco in La Leonesa on his research findings on glyphosate. Three people were seriously injured in the attack and the event had to be abandoned. Carrasco and a colleague shut themselves in a car and were surrounded by people making violent threats and beating the car for two hours.

Witnesses said they believed that the attack was organized by local officials and a local rice producer to protect powerful economic interests behind local agro-industry.

The state authorities have not carried out systematic epidemiological studies in areas where glyphosate spraying is widespread. However, Amnesty said that since Carrasco's research findings were announced, "Activists, lawyers and health workers … have started to conduct their own studies, registering cases of foetal malformations and increased cancer rates in local hospitals."[53]

Other reports of damage to health from spraying of glyphosate

Other reports have emerged from South American countries of serious health and environmental effects from the spraying of glyphosate and other agrochemicals on GM RR soy.

In Paraguay in 2003, an 11-year-old boy, Silvino Talavera, died after being poisoned by agrochemicals sprayed on GM RR soy. The other children in the family were hospitalized and glyphosate was one of three chemicals found in their blood.[54]

A British television documentary on RR soy production in Paraguay, Paraguay's Painful Harvest, reported accusations that agrochemicals sprayed on GM RR soy are causing birth defects. A prominent Brazilian soy farmer interviewed for the programme responded that locals did not like the fact that foreigners are making a success of soy farming in Paraguay and that the chemicals used wouldn't harm a chicken.[55]

In 2009 Dr Dario Roque Gianfelici, a rural physician practicing in a soy farming region of Argentina, published a book, La Soja, La Salud y La Gente, or Soy, Health, and People, on health and environmental problems associated with glyphosate spraying.[56] These include high rates of infertility, stillbirths, miscarriages, birth defects, cancer cases, and streams strewn with dead fish.

An article for New Scientist also reported crop damage, livestock deaths, and health problems in people from glyphosate spraying.[57]

Court bans on glyphosate spraying around the world

Argentina is not the only country in which a court has banned the spraying of glyphosate. In Colombia, in July 2001, a court ordered the government to stop aerial spraying of Roundup on illegal coca plantations on the border of Colombia and Ecuador.[58]

Aerial spraying by the Israeli government of Roundup and other chemicals on crops of Bedouin farmers in the Naqab (Negev), Israel between 2002 and 2004 was stopped by a court order[59 60] after a coalition of Arab human rights groups and Israeli scientists reported high death rates of livestock and a high incidence of miscarriages and disease among exposed people.[61 62]

Epidemiological studies on glyphosate

Epidemiological studies look at a large group of people who have been exposed to a substance suspected of causing harm. The exposed group is compared with an unexposed group that is matched in social and economic terms. The incidence of certain diseases or other negative effects is measured in each group to see whether exposure to the suspect substance is associated with an increase.

Epidemiological studies on glyphosate exposure show an association with serious health problems. Findings include:

- A study found a higher degree of DNA damage in people living in the spray zone near the border compared with those 80 kilometres away.[63] DNA damage may activate genes associated with the development of cancer, lead researcher César Paz y Miño commented, and thus may lead to miscarriage or birth defects.[64] This finding was in addition to the expected symptoms of Roundup exposure – vomiting and diarrhoea, blurred vision, and difficulty in breathing.
- A study of farming families in Ontario, Canada found high levels of premature births and miscarriages in female members of families that used pesticides, including glyphosate and 2,4-D[65] (one of the herbicides that farmers are using to manage glyphosate-resistant weeds).
- An epidemiological study of pesticide applicators found that exposure to glyphosate is associated with higher incidence of multiple myeloma, a type of cancer.[66]
- Studies conducted in Sweden found that exposure to glyphosate is linked with a higher incidence of non-Hodgkin's lymphoma, a type of cancer.[67 68 69]
- Glyphosate promotes skin cancer.[70]

By themselves, these epidemiological findings cannot prove that glyphosate is the causative factor. Manufacturers of substances identified by such studies as potentially harmful often claim that there is no evidence that the substance was the cause of the harm. It is true that epidemiological studies cannot identify cause and effect – they can only point to associations between a suspected causative factor and a health problem. Further toxicological work has to be done to establish cause and effect. However, this limitation of epidemiology does not invalidate its findings. The toxicological studies on glyphosate cited above confirm that it poses health hazards.

Indirect toxic effects of glyphosate

Manufacturers of glyphosate and proponents of GM RR soy claim that glyphosate breaks down rapidly into harmless substances and is not harmful to the environment. But studies show that this is not so.

In soil, glyphosate has a half-life (the length of time it takes to lose half its biological activity) of between 3 and 215 days, depending on soil conditions and temperature.[71 72] In water, glyphosate's half-life is 35–63 days.[73]

Glyphosate and Roundup have toxic effects on the environment. Findings include:

- Glyphosate stimulates growth and development of a type of water snail that is a host of sheep liver fluke. The study concludes that low levels of glyphosate could promote increased liver fluke infections in mammals.[74]
- Glyphosate enhances susceptibility of fish to parasites.[75]

- A three-year study of spruce clearcuts sprayed with glyphosate found that total bird densities decreased by 36 per cent.[76]
- Glyphosate is toxic to earthworms.[77 78]
- After a single glyphosate treatment, mosses needed four years to begin to recover in density and diversity.[79]
- Claims of the environmental safety of Roundup have been overturned in courts in the United States and France. In New York in 1996, a court ruled that Monsanto is no longer allowed to label Roundup as "biodegradable" or "environmentally friendly".[80] In France in 2007, Monsanto was forced to withdraw advertising claims that Roundup was biodegradable and leaves the soil clean after use. The court found that these claims were false and misleading, and fined Monsanto's French distributor 15,000 Euros.[81]

Residues of glyphosate and adjuvants in soy

In 1997, after GM RR soy was commercialized in Europe, the limit on glyphosate residues (maximum residue limit or MRL) allowed in soy was increased 200-fold from 0.1 mg/kg to 20 mg/kg.[82] This high residue limit is not permitted for any other pesticide in the EU or for any other produce.

Similarly, in Brazil in 1998, ANVISA, an agency of the Ministry of Health of the Brazilian Government, authorized a 50-fold increase in the MRL of glyphosate from 0.2 mg/kg to 10 mg/kg.

These increases in the MRL of glyphosate have been criticized as political decisions with no scientific basis. In 1999, Malcolm Kane, who had just retired as head of food safety at the UK supermarket chain Sainsbury's, said in a press interview that the level had been raised to "satisfy the GM companies" and smooth the path of GM RR soy to enter the market.[83]

Glyphosate residues have been found in food and feed. Soybeans have been found to contain glyphosate residues at levels up to 17mg/kg.[84] Residues of glyphosate have been found in strawberries,[85] lettuce, carrots, and barley planted on land previously treated with glyphosate. Glyphosate residues were found in some of these foods even when the crops were planted a year after glyphosate was applied to the soil.[86]

No MRL has been set for glyphosate's main environmental breakdown product or metabolite, AMPA, which has been found in soybeans at high levels of up to 25mg/kg.[87] Monsanto claims that AMPA has low toxicity to mammals and non-target organisms.[88] However, recent research testing the effects of Roundup formulations found that both AMPA and the Roundup adjuvant POEA kill human cells at extremely low concentrations.[89] A study found that AMPA causes DNA damage in cells.[90] POEA is about 30 times more toxic to fish than glyphosate.[91]

HAZARDS OF GENETICALLY MODIFIED CROPS & FOODS

The most obvious risks of GM RR soy relate to the glyphosate herbicide used with the crop. But another set of risks must also be considered: those arising from genetic manipulation.

De-regulation of GM foods

The US Food and Drug Administration (FDA) allowed the first GM foods onto world markets in the early 1990s.

Contrary to claims by the GM industry and its supporters, the FDA has never approved any GM food as safe. Instead, it de-regulated GM foods, ruling that they are substantially equivalent to their non-GM counterparts and do not require any special safety testing. The term "substantial equivalence" has never been scientifically or legally defined. However, it is used to claim (inaccurately) that a GM food is no different from its non-GM equivalent.

The FDA's ruling was widely recognized as an expedient political decision with no basis in science. More controversially, the FDA ignored the warnings of its own scientists that GM is different from traditional breeding and poses unique risks to human and animal health.[92]

Since then, in the US and elsewhere, safety assessment of GM foods has been a voluntary process, driven by the commercializing company. The company chooses which data to submit to the FDA and the FDA sends the company a letter reminding the company that the responsibility to ensure the safety of the GM food in question rests with the company. This process exempts the FDA from liability for damage caused by a GM food.[93]

The precedent set by the FDA has been used to pressurise other countries into authorizing the adoption of GM crops for cultivation – or at least for import as food and feed.

European safety assessment of GM foods

It is often claimed that Europe has more stringent food safety risk assessment standards for GM foods than the US. But this is untrue. The European GM regulator, EFSA (European Food Safety Authority), like the FDA, believes that feeding trials with GM foods are generally unnecessary and bases its assessment of GM foods on the assumption that GM foods are substantially equivalent to their non-GM equivalents.[94]

GM plants are tested much more superficially than irradiated food, pesticides, chemicals and medicines. To prove the safety of irradiated food, for example, feeding trials were conducted on mice, rats, dogs, monkeys and even humans. Feeding trials were performed over several years to investigate growth, carcinogenicity and effects on reproduction. GM plants have undergone no such investigations.[95]

The genetic engineering process

GM proponents often claim that genetic engineering is simply an extension of conventional plant breeding. But this is untrue. GM uses laboratory techniques to insert artificial gene units into the host plant's genome – a process that would never happen in nature. The artificial gene units are created by joining fragments of DNA from viruses, bacteria, plants and animals. For example, the herbicide-resistant gene in GM RR soy was pieced together from a plant virus, two different soil bacteria, and a petunia plant.

The GM transformation process is imprecise and can cause widespread mutations, resulting in potentially major changes to the plant's DNA blueprint.[96] These mutations can directly or indirectly disrupt the functioning and regulation not just of one or even of several, but of hundreds of genes, leading to unpredictable and potentially harmful effects.[97] These can include the production of unexpected toxic, carcinogenic (cancer-causing), teratogenic (causing birth defects) or allergenic compounds.[98]

Unintended changes in GM crops and foods

Several studies show unintended changes in GM crops as compared with the non-GM parent variety. Changes are seen even when the GM and non-GM equivalent varieties are grown side-by-side in identical conditions and harvested at the same time. This shows that any differences are not caused by environmental conditions but by the GM transformation process.

One such carefully controlled study, comparing GM rice with its non-GM equivalent, showed that the two had different amounts of protein, vitamins, fatty acids, trace elements, and amino acids. The authors concluded that the differences "might be related to the genetic transformation".[99]

Another study comparing Monsanto's GM Bt maize MON810 with non-GM equivalent varieties also found unintended changes resulting from the genetic engineering process. The study found that the GM seeds responded differently to the same environment as compared with their non-GM equivalents, "as a result of the genome rearrangement derived from gene insertion".[100]

In some case, such changes do matter, as health hazards can arise from foreign proteins produced in GM plants as a result of the genetic engineering process.[101] In one study, GM peas fed to mice caused immune responses and the mice became sensitized to other foods, though non-GM peas caused no such reaction. Also, kidney beans naturally containing the gene that was added to the GM peas caused no such reaction. This showed that the mice's reaction to the GM peas was caused by changes brought about by the genetic engineering process.[102]

The GM peas were not commercialized. But unexpected ill effects, including toxic effects and immune responses, have been found in animals fed on GM crops and foods that have been commercialized. These include GM maize[103] [104] [105] [106] and canola/oilseed rape[107] as well as soy.

GM foods and crops: The research climate

When GM RR soy was first approved for commercialization, there were few studies on GM foods and crops. Even today, the body of safety data on GM crops and foods is not as comprehensive as it should be, given that they have been in the food and feed supply for 15 years. This is partly because GM companies use their patent-based control of the crops to restrict research. They often bar access to seeds for testing, or retain the right to withhold permission for a study to be published.[108]

Even pro-GM scientists and media outlets have called for more freedom and transparency in GM crop research. An editorial in Scientific American noted, "Unfortunately, it is impossible to verify that genetically modified crops perform as advertised. That is because agritech companies have given themselves veto power over the work of independent researchers."[109]

There is also a well-documented pattern of GM industry attempts to discredit scientists whose research reveals problems with GM crops.[110] For example, UC Berkeley researchers David Quist and Ignacio Chapela found themselves the targets of an orchestrated campaign to discredit them after they published research showing GM contamination of Mexican maize varieties.[111] An investigation traced the campaign back to the Bivings Group, a public relations firm contracted by Monsanto.[112] [113]

In spite of this restrictive research climate and sometimes in the face of strong industry opposition, hundreds of peer-reviewed studies have been carried out on GM foods and crops. Many assess longer-term impacts such as the widespread rise of glyphosate-resistant weeds around the world. The findings show that GM RR soy is not substantially equivalent to non-GM soy, but differs in its properties, effects on experimental animals, environmental impacts, and in-field performance.

Approval of GM RR soy

Monsanto applied for approval of its GM RR soy for commercialization in 1994. It based its application on research that analyzed the composition, allergenicity, toxicity, and feed conversion of RR soybeans, which, taken together, were intended to demonstrate safety to health.

The research was neither peer-reviewed nor published at the time of the application. Related papers by Monsanto employees appeared only later in scientific journals.[114] [115] [116] [117]

Since GM RR soy was commercialized in 1996, scientists have criticized these studies on grounds including the following:[118 119 120 121]

- Data in the published studies differ from data in approval applications.
- Important data on which study conclusions were based were inconsistent or missing.
- Significant differences in the composition of GM and non-GM soy are dismissed in forming a conclusion of substantial equivalence.
- Significant differences found in feeding studies (lower weights and lower feed consumption in male rats and fish, higher kidney/testicle weight in rats, increased milk fat value in cows) between those fed with GM RR soy and those fed the control diet are unjustifiably dismissed as not biologically significant.
- Histological examinations (in which body tissues of experimental animals are examined for changes and toxic effects) were not carried out or are missing from published data.
- No long-term health effects are tested for. These kinds of tests are necessary to find out if GM RR soy has (for example) carcinogenic or reproductive effects.
- The diets fed to experimental animals are such that any effects from GM RR soy would be masked. For example, protein content is so high, and/or levels of GM soy so low, that the chances of finding any differences from the GM RR diet are minimized.

Overall, the methodological flaws bias the studies towards conclusions of "no differences" between GM and non-GM soy.[122 123 124 125]

Unintended changes in GM RR soy

GM RR soy was approved for commercialization in 1996, but independent molecular characterization was only done in 2001. Unpredicted changes in the DNA were discovered. The GM insert had been scrambled and an extra transgene fragment had appeared since it was characterised by Monsanto.[126]

Another study showed that the transgene in GM RR soy does not create RNA (a type of molecule) in the way that was originally intended. The authors conclude that GM crops can produce unnatural, unintended RNA combinations that would give rise to new and unexpected proteins.[127]

These studies show that GM RR soy as it currently exists is not the same as the GM RR soy that Monsanto originally described in its submission for approval to the US FDA.

There are two possible explanations for this. The first is that Monsanto's original data were wrong. The second is that the genetic makeup of GM RR soy is unstable over time and/or varies between different seed lots. Either explanation raises concerns about the safety of GM RR soy and the scientific competence of Monsanto's safety assessment.

Health hazards and toxic effects of GM RR soy

Since GM RR soy was approved for commercialization, studies have found ill effects in laboratory animals fed on GM RR soy, which were not seen in non-GM-fed control groups:

- In a rare long-term feeding study, mice were fed GM soy for 24 months. Significant cellular changes were seen in the liver, pancreas and testes. The researchers found irregularly formed cell nuclei and nucleoli in liver cells, which indicates increased metabolism and potentially altered patterns of gene expression.[128 129 130]
- Mice fed GM soy over their entire lifetime showed more acute signs of ageing in their liver. Several proteins relating to liver cell metabolism, stress response, calcium signalling (involved in controlling muscle contraction) and mitochondria (involved in energy metabolism) were differently expressed in GM-fed mice.[131]
- Rabbits fed GM soy showed enzyme function disturbances in kidney and heart.[132]
- Female rats fed GM soy showed changes in their uterus and ovaries compared with controls fed organic non-GM soy or a non-soy diet.[133]
- In a multigenerational study on hamsters, most of the GM soy-fed hamsters had lost the ability to reproduce by the third generation. The GM-fed hamsters had slower growth and higher mortality among the pups.[134]

The findings suggest that GM RR soy could pose serious health risks to humans. The fact that differences were found between GM-fed and non-GM-fed animals contradicts the FDA's assumption that GM soy is substantially equivalent to non-GM soy.

In most cases it is not clear whether the observed effects are due to the genetic engineering of the soy genome or to the application of glyphosate-based herbicides (and the resulting presence of glyphosate or Roundup adjuvants – or to synergistic GM/glyphosate effects. Further research is needed to separate out the possible effects of these different aspects.

Flawed feeding trial finds no difference between GM and non-GM soy

GM proponents and regulators[135] often claim safety of GM RR soy based on a feeding trial on mice by Brake and Evenson (2004).[136] The study reported no significant differences in the mice fed GM and non-GM soy.

However, the study focused on a narrow area of investigation – testicular development in young male mice – and did not look for toxic effects in other organs and systems. The method of sourcing the GM and non-GM soy was not scientifically rigorous. The authors wrote: "Soybeans were obtained from the 2000 crop from a seed dealer who identified an isolated conventional field and a transgenic soybean field in eastern South Dakota." Samples were taken from the middle of each field. The GM and non-GM soy supplies for the different diets do not appear to have been tested to confirm that they were in fact different.

Several aspects of the study are poorly described. The authors do not state the amount of non-GM soy that was put into the non-GM diet. They do not specify the amount of either diet consumed by the mice. The feeding protocol, weights of each animal, and growth pattern related to feed intake are not recorded. All these factors are relevant to a rigorous nutritional and toxicological study and yet are not accounted for.

For these reasons, it is not possible to make scientifically defensible claims of safety for GM soy based on this study.

Effects of GM animal feed

Around 38 million tons of soymeal per year are imported into Europe, which mostly goes into animal feed. Around 50–65 percent of this is GM or GM-contaminated, with 14–19 million tons GM-free.

Food products from GM-fed animals do not have to carry a GM label. This is based on assumptions including:

- GM DNA does not survive the animal's digestive process
- GM-fed animals are no different from animals raised on non-GM feed
- meat, fish, eggs and milk from animals raised on GM feed are no different from products from animals raised on non-GM feed.

However, studies show that differences can be found in animals raised on GM RR soy animal feed, compared with animals raised on non-GM feed, and that GM DNA can be detected in the milk and body tissues (meat) of such animals. Findings include:

- DNA from plants is not completely degraded in the gut but is found in organs, blood, and even the offspring of mice.[137] GM DNA is no exception.
- GM DNA from GM maize and GM soy was found in milk from animals raised on these GM crops. The GM DNA was not destroyed by pasteurization.[138]
- GM DNA from soy was found in the blood, organs, and milk of goats. An enzyme, lactic dehydrogenase, was found at significantly raised levels in the heart, muscle, and kidneys of kids fed GM RR soy.[139] This enzyme leaks from damaged cells and can indicate inflammatory or other cellular injury.

Health effects on humans

Very few studies directly examine the effects of GM foods on humans. However, two studies examining possible impacts of GM RR soy on human health found potential problems.

Simulated digestion trials show that GM DNA in GM RR soy can survive passage through the small intestine and would therefore be available for uptake by the intestinal bacteria or cells.[140] Another study showed that GM DNA from RR soy had transferred to intestinal bacteria before the experiment began and continued to be biologically active.[141] These studies were not followed up.

GM proponents often claim that GM DNA in food is broken down and inactivated in the digestive tract. These studies show that this is false.

Nutrient value and allergenic potential

- Studies show that GM RR soy can be less nutritious than non-GM soy and may be more likely to cause allergic reactions:
- GM RR soy had 12–14 per cent lower amounts of isoflavones (compounds that have been found to have anti-cancer effects) than non-GM soy.[142]
- The level of trypsin inhibitor, a known allergen, was 27 per cent higher in raw GM soy varieties.[143]
- GM RR soy was found to contain a protein that differed from the protein in wild type soy, raising the possibility of allergenic properties. One of the human experimental subjects in the study showed an immune response to GM soy but not to non-GM soy.[144]

These findings show that GM soy is not substantially equivalent to non-GM soy.

AGRONOMIC & ENVIRONMENTAL IMPACTS OF GM RR SOY

Many of the promised benefits to farmers of GM crops, including GM RR soy, have not materialized. On the other hand, unexpected problems have arisen.

Yield

The claim that GM crops give higher yields is often uncritically repeated in the media. But this claim is not accurate.

At best, GM crops have performed no better than their non-GM counterparts, with GM RR soy giving consistently lower yields. A review of over 8,200 university-based soybean varietal trials found a yield drag of between 6 and 10 per cent for GM RR soy compared with non-GM soy.[145] Controlled comparative field trials of GM and non-GM soy suggest that half the drop in yield is due to the disruptive effect of the GM transformation process.[146]

Data from Argentina show that GM RR soy yields are the same as, or lower than, non-GM soybean yields.[147] In 2009, Brazilian farmer organization FARSUL published the results of trials on 61 varieties of soybean (40 GM and 21 non-GM), showing that the average yield of non-GM soybeans was 9 per cent higher than GM, at a cost equivalent production.[148]

Claims of higher yields from Monsanto's new generation of RR soybeans, RR 2 Yield, have not been borne out. A study carried out in five US states involving 20 farm managers who planted RR 2 soybeans in 2009 concluded that the new varieties "didn't meet their [yield] expectations".[149] In June 2010 the state of West Virginia launched an investigation of Monsanto for false advertising claims that RR 2 soybeans gave higher yields.[150]

A possible explanation for the lower yields of GM RR soy is that the transgenic modification alters the plant's physiology so that it takes up nutrients less effectively. One study found that GM RR soy takes up the important plant nutrient manganese less efficiently than non-GM soy.[151] Another possibility is that the glyphosate used with GM RR soy is responsible for the yield decrease, as it reduces nutrient uptake in plants and makes them more susceptible to disease. A third possibility is that the new added biological function that enables the GM soy to resist glyphosate involves additional energy consumption by the plant. As a result, less energy could be left over for grain formation and maturity. The genetic engineering process permitted a new function, but never made available additional energy.

A US Department of Agriculture report confirms the poor yield performance of GM crops, saying, "GE crops available for commercial use do not increase the yield potential of a variety. In fact, yield may even decrease.... Perhaps the biggest issue raised by these results is how to explain the rapid adoption of GE crops when farm financial impacts appear to be mixed or even negative."[152]

The failure of GM to increase yield potential is emphasised in 2008 by the United Nations IAASTD report on the future of farming.[153] This report, authored by 400 international scientists and backed by 58 governments, says that yields of GM crops are "highly variable" and in some cases, "yields declined". The report notes, "Assessment of the technology lags behind its development, information is anecdotal and contradictory, and uncertainty about possible benefits and damage is unavoidable."

The definitive study to date on GM crops and yield is "Failure to yield: Evaluating the performance of genetically engineered crops",[154] by former US Environmental Protection Agency (EPA) scientist, Dr Doug Gurian-Sherman. It uses data from published, peer-reviewed studies with well-designed experimental controls. The study distinguishes between intrinsic yield (also called potential yield), defined as the highest yield which can be achieved under ideal conditions, and operational yield, the final yield achieved under normal field conditions when crop losses due to pests, drought, or other environmental stresses are factored in.

The study also separates out effects on yield caused by conventional breeding methods and those caused by GM traits. It has become common for biotech companies to use conventional breeding and marker assisted breeding to produce higher-yielding crops and to engineer in their own patented genes for herbicide tolerance or insect resistance. In such cases, higher yields are not due to genetic engineering but to conventional breeding. "Failure to yield" teases out these distinctions and analyzes the contributions made by genetic engineering and conventional breeding to increasing yield.

The study concludes that GM herbicide-resistant soybeans have not increased yields. It further concludes that GM crops in general "have made no inroads so far into raising the intrinsic or potential yield of any crop. By contrast, traditional breeding has been spectacularly successful in this regard; it can be solely credited with the intrinsic yield increases in the United States and other parts of the world that characterized the agriculture of the twentieth century."

The author comments, "If we are going to make headway in combating hunger due to overpopulation and climate change, we will need to increase crop yields. Traditional breeding outperforms genetic engineering hands down."[155]

Glyphosate-resistant weeds

Glyphosate-resistant weeds (superweeds) are the major agronomic problem associated with GM RR soy cultivation. Soy monocultures that focus on a single herbicide, glyphosate, set up the conditions for increased herbicide use. As weeds gain resistance to glyphosate over time, more of the herbicide is required to control weeds. A point is reached when no amount of glyphosate is effective and farmers are forced onto a treadmill of using older, toxic herbicides such as 2,4-D.[156] [157] [158] [159] [160] [161] [162] [163] [164] This increases production costs and environmental degradation.

Many studies confirm that the widespread use of glyphosate on RR soy has led to an explosion of glyphosate-resistant weeds (often called superweeds) in North and South America, as well as other countries.[165] [166] [167] [168] [169] [170] Even a study that broadly supports the notion of the sustainability of GM RR soy concludes, "The introduction of RR soy very likely contributed to the development of glyphosate resistant weed biotypes in Brazil and Argentina."[171]

The Herbicide Resistance Action Committee (HRAC), financed by the pesticide industry, gives data on the development of herbicide resistance in weeds. Its website (www.weedscience.org) lists a total of 19 glyphosate-resistant weeds that have been identified around the world. In the United States, glyphosate-resistant weeds have been identified in 22 states.[172]

It is widely recognized that glyphosate-resistant weeds are rapidly undermining the viability of the Roundup Ready farming model.

In the United States, glyphosate-resistant weeds hit the South first, and it is here that their impact has been most dramatic. In Georgia, tens of thousands of acres of farmland have been abandoned after being overrun by glyphosate-resistant pigweed.[173 174]

The glyphosate-resistant weed problem rapidly expanded to more northerly parts of the United States. In an article called "Roundup's potency slips, foils farmers", Monsanto's hometown newspaper, the St Louis Post-Dispatch, reported glyphosate-resistant weeds in the Midwestern state of Missouri. The article quoted Blake Hurst, a maize and soy farmer and vice president of the board of the Missouri Farm Bureau, as saying that glyphosate-resistant weeds are now a "serious, serious problem" in the state. Hurst warned farmers in the northern states against complacency: "The further north you get, the less of a problem it's been so far. Farmers here are denying it's going to happen to them. But guess what? It's on the way to your farm."[175]

An article in the New York Times confirmed that throughout the East and Midwest, as well as the South, farmers "are being forced to spray fields with more toxic herbicides, pull weeds by hand and return to more labour-intensive methods like regular ploughing". Eddie Anderson, a farmer who has used no-till farming for 15 years but is planning to return to ploughing, said, "We're back to where we were 20 years ago."

The article contained an implied admission by Monsanto that its GM Roundup Ready technology had failed. It said the company is "concerned enough about the problem that it is taking the extraordinary step of subsidizing cotton farmers' purchases of competing herbicides to supplement Roundup."[176] Similarly, the St. Louis Post-Dispatch article said of the Roundup Ready system, "this silver bullet of American agriculture is beginning to miss its mark."[177]

In Argentina, too, glyphosate-resistant weeds are causing problems.[178 179 180] One study described the environmental, agronomic and economic impacts of glyphosate-resistant Johnson grass in the north of the country. First found in 2002, the weed has since spread to cover at least 10,000 hectares. As in North America, farmers have had to resort to non-glyphosate herbicides to try to control the weed.[181]

It has become common for defenders of GM technology to blame farmers for the glyphosate-resistant weed problem on the grounds that they are over-using the herbicide. An article for Nature Biotechnology quoted Michael Owen, a weed scientist at Iowa State University in Ames, as calling GM glyphosate resistance "an incredible technology that is being compromised because of farm management decisions".[182] However, farmers are only cultivating GM glyphosate-resistant crops as they were designed to be grown – by dousing them with a single herbicide, glyphosate.

The industry's only practical response to the superweed problem is more chemicals. A Wall Street Journal report of June 2010, "Superweed outbreak triggers arms race", said that as Roundup fails against increasingly hardy strains of pigweed, horseweed and Johnson grass in America's farm belt, "chemical companies are dusting off the potent herbicides of old for an attack on the new superweeds".

Data from the US Department of Agriculture's National Agricultural Statistics Service (NASS) show that the spread of glyphosate resistant weeds has markedly increased 2,4-D use. NASS data show 2,4-D applications on soybeans rising from 1.73 million pounds in 2005 to 3.67 million pounds in 2006, a 112 per cent increase. In Louisiana in 2006, soybean farmers sprayed 36 per cent of their acres with Paraquat and 19 per cent with 2,4-D.[183]

The chemical companies Dow, DuPont, Bayer, BASF, and Syngenta are now "engineering crop varieties that will enable farmers to spray on the tough old weedkillers freely, instead of having to apply them surgically in order to spare crops", noted the Wall Street Journal report.[184]

Bayer CropScience has patented a GM soy with tolerance to the herbicide glufosinate ammonium, the so-called LibertyLink® or LL soy. LL soy is promoted as an alternative to GM soy for farmers that face weed control problems due to the development of glyphosate-resistant weeds.[185] Glufosinate ammonium is controversial because of research showing it has toxic effects on laboratory animals. It is a neurotoxin[186] and has been found to cause birth defects in mice.[187]

In some cases, the new generation of herbicide-resistant crops will be engineered with "stacked" traits to tolerate multiple herbicides. A study by Plant Research International that supports the sustainability of GM soy recommends this approach: "A mix of crop varieties with tolerance to herbicides other than glyphosate could be integrated in the production system to diversify the use of herbicides as a strategy to slow down build-up of weed resistance."[188]

However, weed scientists have commented that these new GM crops will only buy growers more time until weeds evolve resistance to other herbicides.[189] In fact, a number of weed species resistant to Dicamba and 2,4-D already exist.[190 191]

Clearly, GM herbicide-resistant technology is unsustainable.

Pesticide/herbicide use

Minimizing the use of agrochemicals is a key tenet of sustainability. The GM industry has long claimed that GM crops have decreased pesticide use ("pesticide" is used here in its technical sense to include herbicides, insecticides, and fungicides. Herbicides are, in fact, pesticides).

North America

The agronomist Dr Charles Benbrook examined the claim that GM crops reduce pesticide use in a 2009 report using data from the US Department of Agriculture (USDA) and the USDA's National Agricultural Statistics Service (NASS).[192] Looking at the first thirteen years of GM crop cultivation in the United States (1996–2008), Benbrook found that the claim was valid for the first three years of commercial use of GM herbicide-tolerant and GM Bt maize, GM RR soy, and GM herbicide-tolerant and GM Bt cotton, compared with non-GM maize, soy, and cotton. But since 1999 it has not been true. On the contrary, these GM crops taken together increased pesticide use by 20 per cent in 2007 and by 27 per cent in 2008, compared with the amount of pesticide likely to have been applied in the absence of GM seeds. The increase was due to two factors: the rise in glyphosate-resistant weeds, and the gradual reduction in the rate of herbicides applied to non-GM crop fields.

Bt maize and cotton delivered reductions in chemical insecticide use totaling 64.2 million pounds over the 13 years (though the Bt gene turns the plant itself into a pesticide, a factor that is not taken into account in claims of reduced pesticide application rates with Bt crops). However, GM herbicide-tolerant crops increased herbicide use by a total of 382.6 million pounds over 13 years – swamping the modest 64.2 million pound reduction in chemical insecticide use attributed to Bt maize and cotton.

Recently herbicide use on GM fields has veered sharply upward. Crop years 2007 and 2008 accounted for 46 per cent of the increase in herbicide use over 13 years across the three herbicide-tolerant crops. Herbicide use on GM herbicide-tolerant crops rose 31.4 per cent from 2007 to 2008.

The report concludes that overall, farmers applied 318 million more pounds of pesticides as a result of planting GM seeds over the first 13 years of commercial use. In 2008, GM crop fields required over 26 per cent more pounds of pesticides per acre (1 acre = approximately 0.4 hectares) than fields planted to non-GM varieties.

GM RR soy and herbicide use

Based on NASS data, Benbrook calculates an increase in herbicide use of 41.5 million pounds in 2005 due to the planting of GM RR soy, as compared with non-GM soy (the last NASS survey of soybean herbicide use was in 2006). Over the full 13 years, GM RR soybeans increased herbicide use by 351 million pounds (about 0.55 pounds per acre), compared with the amount that would have been applied in the absence of herbicide-tolerant crops. GM RR soy accounted for 92 per cent of the total increase in herbicide use across the US's three major herbicide-tolerant crops: soy, maize, and cotton.[193]

Claims of herbicide reductions with GM RR soy

In his report, Benbrook takes issue with claims by the part-industry-funded National Center for Food and Agricultural Policy (NCFAP) that GM RR soy has reduced herbicide use as compared with non-GM soy. Benbrook writes that NCFAP underestimates herbicide use on GM herbicide-tolerant acres and overstates the amount applied to conventional acres. These faulty assumptions result in an illusory "reduction" in herbicide use of 20.5 million pounds nationally from the planting of GM RR soy in 2005.

Benbrook also criticizes the findings of a report by PG Economics, a UK-based PR firm commissioned by the GM industry. PG Economics' report estimates a 4.6 per cent reduction worldwide in herbicide use attributable to GM crops from 1996 to 2007 (the first 12 years of commercial use). However, Benbrook points to PG Economics' "creative – and highly questionable – methodological strategies". For example, PG Economics projects an increase in the total rate of herbicide application on conventional acres from 2004 through 2007, despite the continued trend toward greater reliance on low-dose herbicides.[194]

Nevertheless, it is noteworthy that PG Economics' report agrees with Benbrook's findings that GM RR soy has increased herbicide use in the United States by a substantial and growing amount.

South America

In Argentina, according to Monsanto, GM RR soy makes up 98 per cent of the soybean plantings.[195] Here, as in North America, GM RR soy has driven dramatic increases in the consumption of agrochemicals.[196] [197] Pengue (2000) projected that around 42.6 per cent of the herbicides applied by farmers in the late 1990s were used to grow GM RR soy.[198]

Reports published by the Argentine ministry for agriculture, livestock, fisheries and food state that between 1995 and 2001 (in parallel with the expansion of GM soy), the herbicide market grew from 42 to 111.7 million kg/l respectively, whilst the market for insecticides grew within the same period from 14.5 to 15.7 kg/l, and the fungicide market grew from 7.9 to 9.7 million kg/l.[199]

CASAFE (Argentina's crop protection trade association) gathers figures on pesticide and fertilizer sales in Argentina.[200] CASAFE said in its 2000 report that glyphosate-based products accounted for 40.8 per cent of the total volume of pesticides sold. This figure increased to 44 per cent in 2003.[201]

Dr Charles Benbrook analyzed changes in herbicide use in Argentina triggered by the expansion of GM RR soy with no-till between 1996 and 2004, based on data from CASAFE.[202] Benbrook found that the area planted to GM RR soy increased rapidly from 0.4 million hectares in 1996/97 to 14.1 million hectares in 2003/04. Correspondingly, the volume of glyphosate applied to soybeans increased from 0.82 million kg in 1996/97 to 45.86 million kg in 2003/04. Between 1999 and 2003 the volume of glyphosate applied to soy increased by 145 per cent. These increases are to be expected, given the expansion in area planted to GM RR soy. Benbrook commented that during this period as now, nearly all soy in Argentina was GM RR, and all of the increase in glyphosate application was on GM soy acres.[203]

However, another finding is perhaps less expected by those who argue for the sustainability of GM RR soy. This is that the expansion of RR soy has run in parallel with steadily increasing rates of glyphosate applications on soy per hectare. In other words, each year, farmers have had to apply more glyphosate per hectare than the previous year to achieve weed control. The average rate of glyphosate application on soy increased steadily from 1.14 kg/hectare in 1996/97 to 1.30 kg/hectare in 2003/04.

In Brazil, the consumption of glyphosate in the state of Rio Grande do Sul increased 85 per cent between 2000 and 2005, while the area of soy cultivation increased by only 30.8 per cent.[204]

Also, farmers have had to spray more frequently. The average number of glyphosate applications on soy increased each year from 1.8 in 1996/97 to 2.5 in 2003/04.[205] This was due to the rise in glyphosate-resistant weeds, as farmers have had to use more and more glyphosate to control weeds. This is a fundamentally unsustainable approach to soy production.

It is often claimed that rising glyphosate use is positive because it is less toxic than the other chemicals it replaces.[206] But the research findings above ("Toxic effects of glyphosate and Roundup") show that glyphosate is highly toxic.

In addition, claims that the adoption of glyphosate-resistant crops reduces the use of other herbicides are not borne out. Data from CASAFE show that in Argentina, since 2001, the volumes applied of other toxic herbicides have gone up, not down:

- Dicamba, volume applied up 157 per cent
- 2,4-D, volume applied up 10 per cent
- Imazethapyr, over 50 per cent increase in volume applied.[207]
- This is due to farmers resorting to non-glyphosate herbicides to try to control glyphosate-resistant weeds. Benbrook found that the rate of application of non-glyphosate herbicides on GM RR soybeans rose from less than 1 per cent of total use in 1996/97 to 8 per cent of total use in 2003/04.

GM RR soy in Argentina: Ecological and agronomic problems

Serious environmental and agronomic problems have been linked to GM RR soy expansion in South America. Some are common to any agricultural intensification. However, Pengue (2005) identifies the technology package that goes with RR soy – no-till farming and heavy herbicide use – as a further intensification encouraged by GM. Pengue's study of GM RR soy production in Argentina found that it has caused serious ecological and agronomic problems, including:[208]

- The spread of glyphosate-resistant weeds
- Erosion of soils
- Loss of soil fertility and nutrients
- Dependence on synthetic fertilizers
- Deforestation
- Potential desertification
- Loss of species and biodiversity.

Pengue notes that the GM RR soy model has spread not only in the Pampas but also in areas rich in biodiversity, opening a new agricultural frontier in important ecoregions like the Yungas, Great Chaco, and the Mesopotamian Forest. A new word, "pampeanisation", has been coined to describe the process whereby ecoregions that are very different from the Pampas in environmental, social, and economic terms are being transformed to resemble it.

One study examined whether GM soy contributes more to the loss of natural areas than non-GM soy. The study argued that the simplified method of weed control claimed for RR soy could "facilitate the expansion of soy" in wild and difficult-to-cultivate areas. This is because the main hindrance to the cultivation of such areas is weed pressure. Weeds grow more quickly and complete more life cycles per year than in other areas. Chemical weed control makes the initial conversion of such areas relatively easy.[209] However, the inevitable spread of glyphosate-resistant weeds would undermine long-term sustainability.

Impact of broad-spectrum herbicides on biodiversity

Few studies have been carried out on the effects of the broad-spectrum herbicides applied to herbicide-tolerant GM crops on the wildlife and organisms in and around the field. A rare exception was the UK government's farm scale evaluations, carried out over three years. The trials examined the effects on farmland wildlife of different weed management regimes used with GM crops engineered for tolerance to broad-spectrum herbicides, compared with the weed management regimes used with non-GM crops.

The trials looked at the impacts of three types of GM crops: maize, oilseed rape/canola (spring and autumn varieties) and sugar beet. All the GM plants were engineered to tolerate particular herbicides, though only beet was engineered to tolerate glyphosate. This means that the GM fields could be sprayed with a broad-spectrum herbicide, which would kill all plants except the crop.

The researchers measured the effect of growing GM herbicide-tolerant crops on the range of vegetation growing in the trial fields and on their margins. They also assessed the abundance of animal life – including slugs, snails, insects, spiders, birds, and small mammals. The results showed that the cultivation of GM rape and glyphosate-tolerant beet damaged biodiversity. Fewer insect groups, such as bees and butterflies, were recorded among these crops. There were also fewer weed species and weed seeds to provide food for wildlife.[210] [211] [212] [213] [214]

GM maize was found to be better for wildlife than non-GM maize, with more weed species and insects in and around the field. However, the GM maize, engineered to tolerate the herbicide glufosinate ammonium, was measured against a non-GM maize control grown with atrazine, a highly toxic herbicide that was banned in Europe soon after the trials ended. With such a control, it was highly likely that the GM maize would be found to be better for wildlife.[215] [216] [217] [218] [219]

Soil depletion in South America

The expansion of soy monoculture in South America since the 1990s has resulted in an intensification of agriculture on a massive scale. Altieri and Pengue (2005) report that this has resulted in a decline in soil fertility and an increase in soil erosion, rendering some soils unusable.[220] A study of the nutrients of Argentinean soils predicts that they will be totally consumed in 50 years at the current rate of nutrient depletion and increase in soybean area.[221]

In areas of poor soils, within two years of cultivation, synthetic nitrogen and mineral fertilizers have to be applied heavily.[222]

This is an unsustainable approach to soil management from an economic as well as an ecological point of view. One 2003 study estimated that if the depletion of Argentina's soils from RR soy monoculture were compensated with mineral fertilizers, Argentina would need around 1,100,000 metric tons of phosphorus fertilizers at a cost of US$330,000,000 per year.[223]

Nutrient budgets are an ecological accounting system that measures nutrient inputs into soil – fertilizers of all types – against nutrient outputs – what is taken out in the form of crops and organic matter. In Argentina's Pampas, two decades ago, nutrient budgets were stable. This was due to the use of crop and cattle rotation, which allowed nutrient recycling. But since the introduction of RR soy, the country exports a large amount of nutrients with its grains – especially nitrogen, phosphorus, and potassium – that are not replenished, except from the nitrogen derived from atmospheric fixation.[224]

The costs of the resulting degradation of soils are externalized and not considered by markets or governments.[225] Argentina exports yearly around 3,500,000 metric tons of nutrients, increasing its "ecological debt".[226] Soybean accounts for 50 per cent of this value.

According to a report by the Council on Hemispheric Affairs (COHA), RR soy production in Argentina "has produced desertification, deforestation, environmental threats due to the danger of using transgenic products, and a crisis in the meat and milk industries caused by the soy mono-crop".[227]

In a pattern that has become familiar, Monsanto is cited in the COHA article as blaming farmers for problems caused by the RR soy farming model: "Monsanto claims that the soil degradation and use of pesticides is not because of the use of genetically modified soy, but because the farmers do not rotate with other crops in order to allow the soil to recover."[228]

However, farmers appear to have abandoned rotation to accommodate the rapid expansion of the soy market. A report analyzing the impacts of soy production in Argentina noted that a maize-wheat-soy rotation was followed on the high quality cropland of the Pampas region until the late 1990s. Problems associated with monoculture were at that time "virtually unheard of". By 2005, even government scientists were openly admitting to the effects on soil depletion. Miguel Campos, then agriculture secretary, said, "Soya like this is dangerous because of the nutrient extraction… this is a cost that we are not considering when we measure the results."[229]

Glyphosate's impacts on soil and crops

Concerns have grown over the negative effects of glyphosate applications on nutrient uptake in plants, crop vigor and yields, and plant diseases.

Nutrient uptake and crop yields

Glyphosate reduces nutrient uptake in plants. It binds trace elements, such as iron and manganese, in the soil and prevents their transportation from the roots up into the shoots.[230] As a result, GM soy plants treated with glyphosate have lower levels of manganese and other nutrients and reduced shoot and root growth.[231]

Reduced nutrient uptake affects plants in many different ways. For example, manganese plays an important role in numerous processes in plants, such as photosynthesis, nitrogen and carbohydrate metabolism, and defense against diseases.

Lower nutrient levels in plants have implications for humans, as food derived from these crops can have reduced nutritional value.

In an attempt to overcome poor uptake of manganese and improve growth and yields of GM RR soy, farmers are encouraged to use manganese fertilizer.[232] However, if manganese is applied together with glyphosate, GM RR soybeans show a reduced resistance to glyphosate. One study recommends using more glyphosate to try to overcome this effect of the manganese.[233]

The yield decline in GM RR soy may be partly due to glyphosate's negative impact on nitrogen fixation, a process that is vital to plant growth. In young RR soy plants, glyphosate delays nitrogen fixation and reduces growth of roots and sprouts, leading to yield decline. In drought conditions, yield is reduced by up to 25 per cent.[234] The mechanisms for this process may be explained by another study, which found that glyphosate enters the root nodules and negatively affects beneficial soil bacteria that help nitrogen fixation. It inhibits root development, reducing root nodule biomass by up to 28 per cent. It also reduces an oxygen-carrying protein, leghaemoglobin, which helps bind nitrogen in soybean roots, by up to 10 per cent.[235]

Plant diseases

There is a well-documented link between glyphosate and increased plant diseases. Don Huber, plant pathologist and emeritus professor at Purdue University, researched glyphosate's effects for over 20 years. He said, "There are more than 40 diseases reported with use of glyphosate, and that number keeps growing as people recognize the association [between glyphosate and disease]."[236] This may be in part because the reduced nutrient uptake caused by glyphosate makes plants more susceptible to disease.

Study findings on the link between glyphosate and plant diseases include:

- Glyphosate applied to GM RR soy exudes into the rhizosphere (the area of soil around the roots), inhibiting the uptake of important nutrients by non-target plants. These include nutrients essential to plant disease resistance – manganese, zinc, iron, and boron. The authors conclude that glyphosate could cause an increase in plant diseases. They recommend that out of concern for plant and soil health, claims that glyphosate is readily biodegradable and harmless in agricultural use should be reassessed.[237]
- Diseases including take-all in wheat and Corynespora root rot in soy are more severe after glyphosate application.[238] [239]

Many studies show a link between glyphosate applications and Fusarium, a fungus that causes wilt disease and sudden death syndrome in soy plants. Fusarium produces toxins that can enter the food chain and harm humans and livestock. Huber said, "Glyphosate is the single most important agronomic factor predisposing some plants to both disease and toxins [produced by Fusarium]. These toxins can produce a serious impact on the health of animals and humans. Toxins produced can infect the roots and head of the plant and be transferred to the rest of the plant. The toxin levels in straw can be high enough to make cattle and pigs infertile." [240]

Study findings on the link between glyphosate and Fusarium include:

- Glyphosate treatment causes increases in Fusarium infection of roots and sudden death syndrome in GM RR soy and non-GM soy, compared with controls (no herbicide applied).[241]
- Glyphosate application increases frequency of root-colonizing Fusarium in GM RR soy and GM RR maize, compared with non-GM varieties and GM RR varieties not treated with glyphosate. Effects include reduced availability of manganese to the plants and reduced root nodulation (a process vital to nitrogen fixation and plant growth).[242] [243]
- Glyphosate promotes the growth of Fusarium in root exudates of GM RR and non-GM soy. Also, Fusarium growth is higher in GM RR soy exudates than non-GM soy exudates, regardless of glyphosate treatment.[244]
- Glyphosate applications ranging from 18 to 36 months prior to planting and no-till farming systems are among the most important factors in promoting disease, primarily Fusarium head blight, in wheat and barley crops.[245] A separate study found that Fusarium colonization of wheat and barley roots is associated with glyphosate applications prior to planting.[246] An interesting aspect of these findings is the persistent effect of glyphosate on plant growth two or more years after application.

A 2009 review of research on glyphosate's effects on plant diseases concludes, "Extended use of glyphosate can significantly increase the severity of various [plant] diseases, impair plant defence to pathogens and diseases, and immobilize soil and plant nutrients rendering them unavailable for plant use. … Reduced growth, impaired defenses, impaired uptake and translocation of nutrients, and altered physiology of plants by glyphosate can affect susceptibility or tolerance to various diseases." The authors said that glyphosate's toxicity to beneficial soil organisms further reduces the availability of nutrients that are critical for a plant's defense against disease.

The study concludes that glyphosate's tendency to stimulate the growth of fungi and enhance the virulence of pathogens, including Fusarium, could have "serious consequences for sustainable production of a wide range of susceptible crops" and lead to "the functional loss of genetic resistance". The authors warn, "Ignoring potential non-target detrimental side effects of any chemical, especially used as heavily as glyphosate, may have dire consequences for agriculture such as rendering soils infertile, crops non-productive, and plants less nutritious", compromising agricultural sustainability and human and animal health.

The authors note, "The most prudent method to reduce the detrimental effects of glyphosate on GR [glyphosate-resistant] crops will be to use this herbicide in as small a dose as practically needed."[247]

Research findings on glyphosate's effects on crops not publicized

Studies that have found problems with glyphosate's effects on crops have received little media coverage. A researcher whose work found that glyphosate encouraged the growth of root-colonizing Fusarium in GM RR soy and maize[248] said his research received no publicity in the US. Robert Kremer, a microbiologist with the USDA-ARS (US Department of Agriculture- Agricultural Research Service) and an adjunct professor in the Division of Plant Sciences at the University of Missouri, said: "I was working with USDA-ARS to publish a news release … but they are reluctant to put something out. Their thinking is that if farmers are using this (Roundup Ready) technology, USDA doesn't want negative information being released about it. This is how it is. I think the news release is still sitting on someone's desk."[249]

No-till farming with RR soy

It is often argued that GM RR soy is environmentally sustainable because it enables the use of no-till, a farming method that avoids ploughing with the aim of conserving soil. In the GM RR soy/no-till model, seed is planted directly into the soil and weeds are controlled with glyphosate applications rather than mechanical methods.

Advantages claimed for no-till are that it decreases water evaporation and runoff, soil erosion and topsoil depletion.

However, the disadvantages of no-till include soil compaction and increased soil acidity. One report notes that no-till has facilitated the cultivation of natural lands, as in the Pampas of Argentina. This is because the chemical weed control used with no-till makes the initial conversion of such areas relatively easy,[250] though experience with glyphosate-resistant weeds shows that this simplification is short-lived.

Pests and diseases

Studies have found that no-till encourages higher concentrations of pests and diseases, because they overwinter in crop residue left on the soil and spend longer in proximity to the crop.[251] The link between no-till and increased pest and disease problems has been well documented in studies in South America and elsewhere.[252] [253] [254] [255] [256] [257] [258]

Environmental impact

The major drawback of no-till is more abundant weed growth and increased reliance on agrochemicals, since weeding is not done mechanically, but chemically, with herbicides.

Once the energy and fossil fuel used in herbicide production are taken into account, claims of environmental sustainability for GM RR soy with no-till systems collapse.

A report that largely supports the notion that GM RR soy is sustainable analyzed the Environmental Impact Quotient (EIQ) of GM and non-GM soy in Argentina and Brazil. EIQ is calculated on the basis of the impact of herbicides and pesticides on farm workers, consumers, and ecology.

The report found that in Argentina, the EIQ of GM soy is higher than that of conventional soy in both no-till and tillage systems because of the herbicides applied.[259] Also, the adoption of no-till raises the EIQ, whether the soy is GM RR or non-GM.

The authors conclude that the increased EIQ of GM RR soy is due to the spread of glyphosate-resistant weeds, which force farmers to apply more glyphosate.[260]

Fertilizer use

No-till is linked with increased fertilizer application rates in Argentina. This is because in fields that are not tilled, soil nutrient release to the crop after planting is slower. Therefore fertilizers have to be added to compensate.[261]

While fertilizers are added to soil to counteract nutrient depletion, they have their own detrimental effects on soil and crops. Mineral fertilizers inhibit the beneficial soil fungi called arbuscular mycorrhizal fungi (AMF).[262] These soil organisms colonize the roots of crop plants, enhancing nutrient uptake, pest resistance, water usage, soil aggregation, and yield.[263]

Carbon sequestration

GM proponents claim that GM RR soy benefits the environment because it facilitates the adoption of no-till farming, which in turn enables soils to store more carbon (carbon sequestration).[264] This removes carbon from the atmosphere, helping to offset global warming.

However, most studies claiming to show carbon sequestration benefits for no-till only measure the carbon stored in the surface layer of soil (the top 20 cm). Studies that measure soil carbon in deeper levels of soil (up to 60 cm) find very different results.

One study examined 11 soils in the US under a rotation of maize and soybeans. No-till acres were compared with ploughed acres. The study found that soil carbon levels varied, depending on soil type and sampling depth. Stored carbon levels in no-till systems exceeded those of the ploughed systems in five out of 11 soils, but only in the surface layer (0–10 cm depth). Below the 10 cm depth, no-till soils had similar or lower stored carbon levels than ploughed soils. When soil carbon levels were measured up to 60 cm deep, total soil carbon levels in no-till were similar to those of ploughed soils. In some cases, the total soil carbon level in ploughed soil was about 30 per cent higher than in no-till soils.

The authors state that the higher soil carbon levels in ploughed fields may be attributed to incorporation of crop residues in subsoil and deeper root growth. They conclude that no-till farming increases soil carbon concentrations in the upper layers of some soils, but when the entire soil profile is considered, no-till soil does not store more carbon than ploughed soil.[265 266]

A separate review of the scientific literature also found that no-till fields sequestered no more carbon than ploughed fields when carbon changes at soil depths greater than 30 cm are examined. In fact, on average, the no-till systems may have lost some carbon over the period of the experiments.

The authors explain that studies claiming to find carbon sequestration benefits from no-till only measure carbon sequestration down to about 30 cm do not give an accurate picture. This is because the roots of crops – which deposit carbon in the soil – often grow much deeper. When carbon changes at soil depths greater than 30 cm were examined, most (35 of 51) of the studies reviewed found no significant difference in carbon sequestration between ploughing and no-till.[267]

- On the other hand, a number of biological, soil-based, integrative farm practices do sequester more carbon:
- A comparison between conventional no-till and organic ploughed systems found that organic ploughed systems sequester more carbon even when the sampling is restricted to shallow soil, where no-till tends to show carbon accumulation.[268]
- The most promising systems for carbon sequestration in soil combine crop rotation and low or no inputs of pesticides, herbicides, and synthetic fertilizers. Long-term studies suggest that such systems build (not simply conserve) significant quantities of soil organic carbon through a variety of mechanisms such as more abundant mycorrhizal fungi.[269 270 271 272]
- A comparison between maize/soybean rotations in conventional tillage and strip tillage (a conservation tillage practice in which most of the soil surface is left undisturbed) found no carbon sequestration benefit from the conservation tillage. Both systems were small net sources of carbon over the 2-year period of the study.[273]
- A study of CO2 exchange between the land surface and the atmosphere was carried out on three adjacent fields, all in no-till. One was in irrigated continuous maize, one in irrigated maize/soybean rotation, and the other in dryland maize. The authors conclude that all were either carbon-neutral or slight sources of carbon.[274]
- These studies show that the claimed benefits of no-till for climate change are overstated at best and misleading at worst.

Energy use

It is often claimed that no-till with GM RR soy farming model saves energy because it reduces the number of times the producer must pass across the field with the tractor. However, data from Argentina show that, while no-till reduces farm operations (tractor passes), these energy savings are wiped out when the energy used in the production of herbicides and pesticides applied to GM soy is taken into account. When these factors are considered, the production of RR soy requires more energy than the production of conventional soy.[275]

Soil and water conservation

A review of the scientific literature and on-farm practice in Brazil challenges even the most commonly claimed benefits for no-till, namely soil and water conservation. The study found that no-till in itself, without soil cover (for example, if residues are burnt, grazed, or removed from the field), can lead to worse soil degradation and crop productivity than ploughing. On some types of soil, such as sandy soils or those that form dense crusts, leaving land unploughed means that it can lose more water and topsoil through runoff than if it were ploughed.[276] Such soils do not benefit from no-till systems.

Summary of problems with no-till/GM soy model

There are sound ecological and agronomic benefits to no-till when it is part of a wider approach to sustainable farming methods. But the no-till with glyphosate farming model that accompanies GM RR soy is unsustainable. It has been found to:

- degrade the environment by encouraging conversion of natural lands to agriculture
- increase pest and disease problems
- cause weed problems
- escalate the use of herbicides
- increase the environmental impact of soy production
- increase fertilizer use
- increase energy use.

Claims that no-till increases carbon sequestration in soils are misleading. Even claimed benefits of no-till for soil and water conservation are not universal but depend on soils and farm practices.

Argentina: The soy economy

Argentina is frequently cited (for example, by the GM industry-supported group ISAAA[277]) as an example of the economic success of the GM RR soy model. According to a report by PG Economics, a PR firm commissioned by the GM industry, the impact of GM RR soy on farm income has been "substantial, with farmers deriving important cost saving and farm income benefits".[278]

There is no doubt that the rapid expansion of GM RR soy in Argentina since 1996 has brought economic growth to a country in a deep recession. The government remains enthusiastic about the soy economy, in part because it has levied export taxes on soybeans that reached 35 per cent in 2010.[279]

However, the soy boom represents a fragile and limited type of success, which is heavily dependent on soy exports and vulnerable to volatile world soy markets.[280] Over 90 per cent of the soy grown in Argentina is exported for animal feed and vegetable oil. Argentina is the world's leading exporter of soybean oil and meal.[281]

More seriously, critics of the soy economy say it has had severe social and economic impacts on ordinary people. They say it has decreased domestic food security and food buying power among a significant sector of the population, as well as promoting inequality in wealth distribution.[282] [283] These trends have led to predictions that the economic model is an unsustainable one of "boom and bust".[284]

A 2005 study by Pengue linked GM RR soy production to social problems in Argentina, including:[285]

- Displacement of farming populations to the cities of Argentina
- Concentration of agricultural production into the hands of a small number of large-scale agribusiness operators
- Reductions in diversity of food production and loss of access by many people to a varied and nutritious diet.

Pengue noted that since the introduction into Argentina of RR soy in 1996, the expansion of GM RR soy monoculture had damaged food security by displacing food crops. Soy production had, in the five years prior to 2005, displaced 4,600,000 hectares of land previously dedicated to other production systems such as dairy, fruit trees, horticulture, cattle, and grain.[286]

Argentine government statistics give the details of this process. The potato harvest fell abruptly from 3.4 million tons in 1997/98 to 2.1 million in 2001/02. Production of green peas fell from 35,000 tons in 1997/98 to 11,200 tons in 2000/01, and lentils from 9,000 tons to 1,800 tons. The production of dry beans, animal protein, eggs, and dairy products similarly fell precipitously – closely synchronized with the expansion of soy production.[287]

Government statistics show that between 1996 and 2002 the number of people lacking access to a "Basic Nutrition Basket" (the government's measure of poverty) grew from 3.7 million to 8.7 million, or 25 per cent of the population. By the second half of 2003, over 47 per cent of the population was below the poverty line and lacked access to adequate food.[288]

By late 2003, incidence of indigence among children under 14 years old was 2.5 times higher than among older people. Poverty and indigence hit rural populations most severely, contributing to displacement of rural populations to the cities.[289]

GM RR soy production is a form of "farming without farmers" and has caused unemployment problems. In GM RR soy monocultures, labour levels decrease by between 28 per cent and 37 per cent, compared to conventional farming methods.[290] In Argentina, high-tech RR soy production needs only two workers per 1000 hectares per year.[291]

The expansion of no-till and herbicide-resistant soy monoculture has led to a rise in unemployment as many small- to mid-size farmers have lost their jobs. Unemployment increased from 5.3 per cent in October 1991 to a peak of 22 per cent in May 2002, falling in subsequent months to below 20 per cent, but remaining disproportionately high in rural areas.[292] The undersecretary of agriculture stated that for every 500 hectares turned over to soy cultivation in Argentina, only one job is created on the farm.[293]

The growing demand for biofuels has worsened Argentina's ecological and social problems by providing new markets for GM RR soy and maize.[294]

The Argentine government recognizes that soy expansion has triggered social problems[295] and that the tendency toward "farming without farmers" must be reversed in order to restore the social sustainability of the agricultural sector.[296]

A major factor in the growth of South America's animal feed export market was the concern in importing countries over BSE (mad cow disease), which in 2000 suddenly ended the use of many domestically-derived animal byproducts and recycled food and agricultural wastes in animal feed.[297] [298] It is likely that animal feed policies will change in the face of pressure for greater self-sufficiency in food production.

Economic impacts of GM RR soy on US farmers

A study using US national survey data found no significantly increased on-farm profits from the adoption of GM RR soy in the US.[299]

A 2006 report for the European Commission on GM crop adoption worldwide concluded that economic benefits of GM crops for farmers were "variable". It said that adoption of GM RR soy in the US "had no significant effect on on-farm income".

In light of this finding, the report asks, "Why are US farmers cultivating HT [herbicide-tolerant, GM RR] soybean and increasing the HT soybean area?" The authors conclude that the high take-up of the crop is due to "crop management simplification".[300] This is a reference to simplified weed control using glyphosate herbicides. But four years on from the report's publication, the explosion of glyphosate-resistant weeds has made even the claim of simplified weed control difficult to justify.

The report asks whether lower costs on weed control and tillage claimed for GM RR soy outweigh "higher seed costs and the fairly small or no differences in yield". It cites a study on US farmers growing the crop, which found that in most cases the cost of the technology was higher than the cost savings. Therefore the adoption of GM RR soy had a negative economic impact, compared to the use of conventional seeds.[301]

RR seed price rises in the US

A 2009 report[302] showed that GM seed prices in the US have increased dramatically compared to non-GM and organic seeds, cutting average farm incomes for US farmers growing GM crops. In 2006, the GM RR soybean seed price premium relative to the price of soybeans had reached 4.5. The conventional seed-to-soybean price premium was 3.2.

The report said: "Farmers purchasing the most closely followed new soybean seed product in 2010 – Monsanto's Roundup Ready (RR) 2 soybeans – will pay 42 per cent more per bag than they paid for RR soybeans in 2009. The RR 2 soybean seed-to-soybean price ratio will be around 7.8, over three times the historic norm.

"In the 25 years from 1975 through 2000, soybean seed prices rose a modest 63 per cent. Over the next ten years, as GE soybeans came to dominate the market, the price rose an additional 230 per cent. The $70 per bag price set for RR 2 soybeans in 2010 is twice the cost of conventional seed and reflects a 143 per cent increase in the price of GE seed since 2001."

The report concluded, "At the present time there is a massive disconnect between the sometimes lofty rhetoric from those championing [GM] biotechnology as the proven path toward global food security and what is actually happening on farms in the US that have grown dependent on GM seeds and are now dealing with the consequences."

It is reasonable to ask why farmers pay such high prices for seed. Recent events suggest that they have little choice. The steep price increases for RR 2 soybeans and "SmartStax" maize seeds in 2010 triggered an antitrust investigation by the US Department of Justice into the consolidation of big agribusiness firms that has led to anti-competitive pricing and monopolistic practices. Farmers have been giving evidence against firms like Monsanto.[303] [304]

Perhaps as a result of the Department of Justice investigation, Monsanto announced in August 2010 that it would cut price premiums on its seed by up to 75 per cent. It remains to be seen how long this effect will last, as some analysts believe the price cut was a strategic "bid to combat market-share gains by rival DuPont Co."[305]

Farmers moving away from GM RR soy

In recent years, reports have emerged from North and South America suggesting that farmers are moving away from GM RR soy.

"Interest in non-genetically modified soybeans growing", was the title of a report from the Ohio State University extension service in 2009. The report said that the growing interest stemmed from "cheaper seed and lucrative premiums [for non-GM soybeans]". In anticipation of this growth in demand, the Ohio State extension service reported that seed companies were doubling or tripling their non-GM soybean seed supply for 2010.[306]

Similar reports emerged from Missouri and Arkansas.[307] [308] Agronomists pointed to three factors driving this renewed interest in conventional soybean seed:

- The high and rising price of RR seed
- The spread of glyphosate-resistant weeds
- Farmers' desire to regain the freedom to save and replant seed, a traditional practice prohibited with Monsanto's patented RR soybeans.

In Brazil's top soy state of Mato Grosso, farmers are also reported to be favouring conventional seeds due to poor yields from GM seeds.[309]

Due to ongoing consumer rejection of GM crops and foods in Europe, non-GM soy is still being grown in Brazil, North America, and India in sufficient quantities to meet the total demand of the European Union.

Farmers' access to non-GM seed restricted

As farmers attempt to regain power of choice over seed, Monsanto is trying to take it away by restricting access to non-GM varieties. In Brazil, the Brazilian Association of Soy Producers of Mato Grosso (APROSOJA) and the Brazilian Association of Non Genetically Modified Grain Producers (ABRANGE) have complained that Monsanto is restricting the access of farmers to conventional (non-GM) soybean seeds by imposing sales quotas on seed dealers, requiring them to sell 85 per cent GM RR soy seed and no more than 15 per cent non-GM.[310]

This mirrors strategies that Monsanto has used in the US and elsewhere to drive penetration of its technologies into the marketplace. Typically, when the company gains sufficient control over the seed sector through acquisition and other strategies, it begins to set quotas that drive sales of its GM seeds and progressively reduce access to non-GM seed.

Monsanto's domination of agriculture in Argentina

In recent years, Argentina has been a target for Monsanto's heavy-handed attempts to dominate global seed and glyphosate supplies. The company has been trying for several years to collect royalties on GM RR soy seed in the country, where it does not have a patent. Its seeds were sold there under licence by a US company that was subsequently acquired by seed and grain importer Nidera. Instead of collecting royalties, Monsanto has made its profits in Argentina from its Roundup herbicide, used with GM RR soy.[311]

In Europe, however, Monsanto does have a patent on GM RR soy. In 2004 Monsanto announced that it was suspending its soy business in Argentina because it was "simply not profitable for us". The following year, Monsanto attempted to recoup its lost royalties by filing lawsuits against European soy importers in the Netherlands and Denmark, accusing them of illegally importing soy meal from its patented GM soybeans from Argentina.[312 313] Monsanto's move threatened Argentina's agriculture, economy, and soy export market. It failed only when the European Court of Justice ruled against the company.[314]

Monsanto said in a press release that it "simply wanted to be paid for the use of [its] technology," adding that since the growers who use the technology in Argentina do not pay for it, "Monsanto has looked [through this case] for alternative ways to collect for the use of our technology and obtain a return on its research investment."[315]

The incident shows the danger of allowing a single entity – Monsanto – to gain near-monopolistic control over seed and agrochemicals markets.

GM contamination and market losses

Consumers and policy makers in many areas of the world reject GM foods. As a result, several instances of GM contamination have severely impacted the industry and markets.

Contamination with unapproved GMOs threatens the entire food sector. Examples include:

- 2009: An unauthorized GM flax, interestingly named CDC Triffid, was found to have contaminated Canadian flax seed supplies. Following the discovery, Canada's flax export market to Europe collapsed.[316 317]
- 2006: Bayer's GM LL601 rice, which was grown for only one year in field trials, was found to have contaminated the US rice supply and seed stocks.[318] Contaminated rice was found as far away as Africa, Europe, and Central America. In March 2007 Reuters reported that US rice export sales were down by 20 per cent from the previous year as a result of the GM contamination.[319] One report estimated the total costs incurred worldwide as a result of the contamination as between $741 million and $1.285 billion.[320] Since the contamination was found, Bayer has been mired in litigation brought by affected US rice farmers. In July 2010 the company lost its fifth straight court case to a Louisiana farmer and was ordered to pay damages of $500,248. The company previously lost two trials in state courts and two in a federal court, resulting in jury awards of over $52 million. It faces about 500 additional lawsuits in federal and state courts with claims by 6,600 plaintiffs. The company has not won any rice trials so far.[321]
- 2000: GM StarLink maize, produced by Aventis (now Bayer CropScience), was found to have contaminated the US maize supply. StarLink had been approved for animal feed but not for human consumption. The discovery led to massive recalls of StarLink-contaminated food products across the US, spreading to Europe, Japan, Canada, and other countries. The discovery led to massive recalls of StarLink-contaminated food products worldwide. The incident was estimated to have lost US producers between $26 and $288 million in revenue.[322]

The unpopularity of GM foods with European consumers means that GM contamination of non-GM foods threatens GM-free markets. Examples include:

- In Canada, contamination from GM oilseed rape has destroyed the market for organic and non-GM oilseed rape.[323]
- GM RR soy is approved for import into Europe. Most of it is used for animal feed. The meat, dairy products, and eggs from GM-fed animals do not have to carry a GM label. Only farmers know what their animals are fed with – not consumers. It is only this "labelling gap" that enables market access for GM crops in Europe.
- Under the German "Ohne Gentechnik" and the Austrian "Gentechnik-frei erzeugt" programmes, and also for retailers such as Marks & Spencer in the UK, animal products are sold as produced with non-GM feed. Contamination from GM RR soy is unacceptable for these market sectors.

Producers and others in the supply chain recognize that discovery of GM contamination could compromise consumer confidence and goodwill. This in turn can result in damaging economic impacts.

HUMAN RIGHTS VIOLATED

Paraguay: Violent displacement of people

Paraguay is one of the world's leading suppliers of GM RR soy, with a projected 2.66 million hectares of the crop in 2008, up from 2.6 million hectares in 2007. Around 95 per cent of the total soybean plantings are GM RR soy.[324]

The expansion of soy in the country has been linked to serious human rights violations, including incidents of land grabbing. A documentary for Channel 4 television in the UK, Paraguay's Painful Harvest, described how the industrial farming of GM RR soy had led to violent clashes between peasant farmers (campesinos), foreign landowners and the police. One interviewee was Pedro Silva, a 71-year-old peasant who was shot five times by unknown assailants after he refused to sell his smallholding to a soy farmer.[325]

According to a 2009 photo-essay by Evan Abramson for the North American Congress on Latin America (NACLA) Report:

"The soy boom has been disastrous for small farmers, who, after living for years on government-allotted forestland, have begun to be uprooted. In the last decade, the Paraguayan government has given away or illegally sold this public land to political friends in the soybean business, pushing the peasants out. Today, about 77 per cent of Paraguayan land is owned by 1 per cent of the population … Since the first soy boom in 1990, almost 100,000 small-scale farmers have been forced to migrate to urban slums; about 9,000 rural families are evicted by soy production each year."[326]

In some land grabs, rural people have reportedly been driven out by armed guards hired by those seizing land. Another way is for landowners to plant GM RR soy right up to the doors of their homes and carry out aerial spraying with glyphosate and other chemicals, forcing them to move away. [327]

An article titled "The soybean wars" for the Pulitzer Centre on Crisis Reporting cites a report from the Union of Journalists of Paraguay (Sindicato de Periodistas del Paraguay) claiming that the Paraguayan press refuses to cover deaths or diseases relating to agrochemical spraying, thus protecting the image of multinational seed and chemical companies.[328]

Abramson also says that there is widespread censorship of the health effects of glyphosate spraying in the news media: "Although locals frequently complain of headaches, nausea, skin rashes, vision problems, and respiratory infections – as well as a suspiciously high incidence of birth defects in soy-producing regions – such reports seldom make it into Paraguay's news media. In the days following a fumigation, it is also common for farmers' chickens to die, and for the cows to abort their calves and their milk to dry up. The non-soy crops that farmers produce for their own consumption also perish."

Abramson tells how two farmer brothers sold their land once crop spraying in the area began. "It's either leave, or stay and die," said one. Their town, once with a population of several hundred, was virtually gone, with almost all of its territory given over to soy plantations.

Some displaced peasant farmers are trying to regain control of land through "land invasions". Abramson reports: "Land invasions generally have an ecological as well as a social character: Landless farmers not only demand land to work, but also protest the soy producers' widespread deforestation and use of agrochemicals."[329]

According to the Pulitzer Centre on Crisis Reporting, the Paraguay government has used the military to quash the land invasions.[330]

CONCLUSION

The cultivation of GM RR soy endangers human and animal health, increases herbicide use, damages the environment, reduces biodiversity, and has negative impacts on rural populations. The monopolistic control by agribusiness companies over GM RR soy technology and production endangers markets, compromises the economic viability of farming, and threatens food security.

In light of these impacts, it is misleading to describe GM RR soy production as sustainable and responsible. To do so sends a confusing message to consumers and all in the supply chain, interfering with their ability to identify products that reflect their needs and values.

Proponents of GM RR soy are invited to address the arguments and scientific findings in this paper and to join in a transparent, science-based inquiry into the principles of sustainability and soy production.

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260. Bindraban and colleagues acknowledge in their study that their findings run counter to those of an earlier paper by Brookes and Barfoot (Brookes, G. & Barfoot, P. 2006. GM crops: the first ten years – global socio-economic and environmental impacts. ISAAA Brief 36), which found a small decrease in field EIQ when RR soy is adopted. However, Brookes and Barfoot used different sources of data – Kynetic, AAPRESID and Monsanto Argentina, whereas Bindraban and colleagues used the agricultural journal AGROMERCADO as their source. Brookes and Barfoot’s data sources give lower glyphosate and 2,4-D application rates. Brookes and Barfoot are not scientists but run a PR company (PG Economics) that works for biotech companies, and their paper was written for the industry lobby group ISAAA. There is no indication that it was peer-reviewed.

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