The Case for

A GM-Free Sustainable World

Independent Science Panel

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Preface

Members of the Independent Science Panel (ISP) on GM have had the opportunity to review extensive scientific and other evidence on genetic engineering over the past decades. Many are among the 579 scientists from 71 countries who have signed a 'World Scientist Statement and Open Letter' [1], initiated in 1999, which called for a moratorium on the environmental release of genetically modified organisms (GMOs), a ban on patents on living processes, organisms, seeds, cell lines and genes, and for a comprehensive public enquiry into the future of agriculture and food security.

Scientific and other developments since 1999 have confirmed our concerns over the safety of genetic engineering, GM crops and food security. At the same time, the successes and benefits of all forms of sustainable agriculture are undeniable. The evidence, now assembled, makes a strong case for a worldwide ban on GM crops to make way for a comprehensive shift to agroecology, sustainable agriculture and organic farming.

The evidence on why GM crops are not a viable option for a sustainable future is presented in Parts 1 and 2 while Part 3 presents evidence on the successes and benefits of sustainable agricultural practices.

Part 1: No Future for GM crops

One

Why Not GM Crops?

GM crops are neither needed nor wanted

There is no longer any doubt that GM crops are not needed to feed the world, and that hunger is caused by poverty and inequality, and not by inadequate production of food. According to estimates by the United Nations Food and Agricultural Organisation, there is enough food produced to feed *everyone using only conventional crops*, and that will remain the case for at least 25 years and probably far into the future [2]. Furthermore, as Altieri and Rosset have argued, even if hunger is due to a gap between food production and human population growth, current GM crops are not designed to increase yields or for poor small farmers, so they are unlikely to benefit from them [3]. Because the true root cause of hunger is inequality, any method of boosting food production that deepens inequality is bound to fail to reduce hunger [4].

More importantly, GM crops are not wanted, and for good reasons. GM crops have failed to deliver the promised benefits, they are causing escalating problems on the farm, and evidence of the worst hazards has accumulated despite the notable lack of research on safety. At the same time, extensive evidence has emerged on the success of sustainable approaches to agriculture, which makes clear what the rational choice for the nation ought to be.

The world market for GM crops has been shrinking simultaneously as the acreage increased sharply since the first GM crop, the Flavr Savr tomato, was planted in the United States in 1994, a product soon withdrawn as a commercial disaster. During the seven-year period from 1996 to 2002, the global acreage of GM crops increased from 1.7 million hectares to 58.7 million hectares. But only four countries accounted for 99% of the global GM crop acreage in 2002. The United States grew 39.0 million hectares, (66% of global total), Argentina 13.5 million hectares, Canada 3.5 million hectares and China 2.1 million hectares [5].

Worldwide resistance to GM reached a climax last year when Zambia refused GM maize in food aid despite the threat of famine. As we are drafting this report, an indefinite hunger strike is in progress in the Philippines, led by a member of the ISP, Roberto Verzola, Secretary-General of the Philippine Greens, in protest of the commercial approval of Monsanto's Bt maize. The Institute of Science in Society (ISIS), which coordinated the drafting of this report, has written to ask the Philippine President to reconsider her decision, and has sent her a copy of this report.

The agricultural sector led the dramatic decline of the biotech industry, before the industry peaked in 2000 on the back of the human genome project. ISIS has summarised the evidence in a special briefing to the UK Prime Minister's Strategy Unit on GM, submitted in response to its public consultation on the economic potential of GM crops [6]. Things have got worse since for the entire industry [7].

A report released in April 2003 by Innovest Strategic Value Advisors [8] gave Monsanto the lowest possible rating with the message that agricultural biotechnology is a high-risk industry not worth investing in, unless it changes its focus away from GE (genetic engineering, synonymous with GM). The report states,

"Money flowing from GE companies to politicians as well as the frequency with which GE company employees take jobs with US regulatory agencies (and vice versa) creates large bias potential and reduces the ability of investors to rely on safety claims made by the US Government. It also helps to clarify why the US Government has not taken a precautionary approach to GE and continues to suppress GE labelling in the face of overwhelming public support for it. With Enron and other financial disasters, the financial community apparently bought into company stories without looking much below the surface....."

"Monsanto could be another disaster waiting to happen for investors", the report concludes.

GM crops failed to deliver the benefits

GM crops have simply not delivered the promised benefits. That is the consistent finding of independent research and on-farm surveys, reviewed by agronomist Charles Benbrook in the United States since 1999 [9, 10] and other studies have borne this out [11]. Thousands of controlled trials of GM soya gave significantly decreased yields of between 5 to 10%, and in some locations, even 12 to 20% compared with non-GM soya. Similar reductions in yield have been reported in Britain for GM winter oilseed rape and sugar beet in field trials.

GM crops have not resulted in significant reductions in herbicide and pesticide use. Roundup Ready soya required 2 to 5 times more herbicide than other weed management systems. Similarly, USDA data suggest that in 2000, the average acre of RR maize was treated with 30% more herbicide than the average acre of non-GM maize.

Analysis of 4 years of official USDA data on insecticide use shows a pretty clear picture [10]. While Bt cotton has reduced insecticide use in several states, Bt corn has had little if any impacts on corn insecticide use. USDA data show that corn insecticide applications directly targeting the European corn borer increased from about 4% of acres treated in 1995 to about 5% in 2000.

The greater cost of GM seeds, the increased herbicide/pesticide use, yield drag, royalties on seed and reduced markets, all add up to lost income for farmers. The first farm-level economic analysis of Bt maize in the US revealed that between 1996 and 2001, the net loss to farmers was $92 million or about $1.31 per acre.

A UK Soil Association report [12] released in September 2002, estimated that GM crops have cost the United States $12 billion in farm subsidies, lost sales and product recalls due to transgenic contamination. It summed up as follows:

“The evidence we set out suggests that….virtually every benefit claimed for GM crops has not occurred. Instead, farmers are reporting lower yields, continuing dependency on herbicides and pesticides, loss of access to markets and, critically, reduced profitability leaving food production even more vulnerable to the interests of the biotechnology companies and in need of subsidies.”

These studies have not taken into account crop failures elsewhere in the world, the most serious in India last year [13]. Massive failures of GM cotton, up to 100%, were reported in several Indian States, including failure to germinate, root-rot and attacks by the American bollworm, for which the Bt-cotton was supposed to be resistant.

Two

Escalating Problems on the Farm

Transgenic Instability

The massive failures of GM cotton in India, and of other GM crops elsewhere are most likely due to the fact that GM crops are overwhelmingly unstable, a problem first highlighted in a 1994 review by Finnegan and McElroy [14]:

> "While there are some examples of plants which show stable expression of a transgene these may prove to be the exceptions to the rule. In an informal survey of over 30 companies involved in the commercialisation of transgenic crop plants….almost all of the respondents indicated that they had observed some level of transgene inaction. Many respondents indicated that most cases of transgene inactivation never reach the literature."

There is, nevertheless, a substantial scientific literature on transgenic instability [15, 16]. Whenever the appropriate molecular tools have been applied to investigate the problem, instability is invariably found, and that is so even in cases where transgenic *stability* has been claimed. In one publication [17] stating in the abstract that "transgene expression was stable in lines of all the rice genotypes", the data presented actually showed that *at most 7 out of 40 (18%) of the lines may be stable to the R3 generation* [18]. This paper, like many others, also misused the failure to deviate significantly from arbitrarily set 'Mendelian ratios' as a sign of Mendelian inheritance, or genetic stability. This is such an elementary mistake in statistics and genetics that students could fail an exam for it.

There are two major causes of transgenic instability. The first has to do with the defence mechanisms protecting the integrity of the organism that 'silence' or inactivate foreign genes integrated into the genome, so that they are no longer expressed. Gene silencing was first discovered in connection with integrated transgenes in the early 1990s, and is now known to be part of the organism's defence against viral infections.

The second major cause of instability has to do with the *structural* instability of the transgenic constructs themselves, their tendency to fragment, to break along weak artificial joints and to recombine incorrectly, often with other DNA that happens to be around. That's perhaps the more serious from the safety point of view, as it enhances horizontal gene transfer and recombination (see later).

Yet another source of instability has been more recently discovered [15]. There appear to be certain ‘receptive hotspots’ for transgenic integration in both the plant and the human genomes. These receptive hotspots may also be ‘recombination hotspots’, prone to breaking and rejoining. That, too, would make inserted transgenes more likely to come loose again, to recombine, or to invade other genomes.

Investigations also show that transgene instability may arise in later generations, and are not necessarily ‘selected out’ during early generations of growth. This can result in poor and inconsistent performances of the GM crops in the field, a problem likely to be underreported by farmers who settle for compensation with a gagging clause.

Volunteers and weeds

Triple herbicide-tolerant oilseed rape volunteers were first discovered in Alberta, Canada in 1998, just two years after single herbicide-tolerant GM crops were planted [19]. A year later, these multiple herbicide tolerant volunteers were found in 11 other fields [20]. The United States only started growing herbicide-tolerant GM oilseed rape in 2001. Research in Idaho University reported finding similar multiple gene-stacking had occurred in experimental plots over two years, and during the same period, weeds with two herbicide tolerant traits were also found.

Many other problems with weeds have been identified since (summarised in ref. 21). Glyphosate-resistant marestail infested over 200 000 acres of cotton in west Tennessee, USA in 2002, or 36% of all cotton acreage in the state, and some 200 000 acres of soya beans were also affected. The problem with herbicide-tolerant volunteers and weeds is such that companies have been recommending spraying with additional herbicides. US agricultural experts reveal that between 75% and 90% of GM maize growers are using a product called Liberty ATZ - a mixture of Aventis’ weed killer glufosinate ammonium and Atrazine, the traditional herbicide used on maize crops that has been a problem pesticide for decades [22]. Atrazine is on Europe's Red List and Priority List for hormone disrupting effects in animals. Glufosinate itself is far from benign (see later).

Bt crops are also experiencing problems with resistance developing in target pests (see below). A new patent application from Monsanto is based on using two insecticides with their Bt crops, on grounds that Bt-crops produce resistant strains of insect pests and “numerous problems remain...under actual field conditions”.

Recent research shows that transgenes from Bt sunflower crossing into wild relatives made the latter hardier and more prolific, with the potential of becoming super-weeds [23].

Bt resistance

Bt crops are genetically engineered to produce insecticidal proteins derived from genes of the bacterium *Bacillus thuringiensis* (Bt). The likelihood of target pests of Bt crops developing resistance to Bt toxins rapidly is so great and real that in the United States, resistance management strategies are adopted, involving planting ‘refugia’ of non-Bt crops and developing Bt crops with high levels of expression, or multiple toxins in the same crop.

Unfortunately, pests have developed resistance to multiple toxins, or cross resistances to different toxins [24], and recent research reveals that resistant strains are even able to obtain additional nutritional value from the toxin, thus making them more serious pests than before.

Extensive transgenic contamination

In November 2001, Berkeley plant geneticists Ignacio Chapela and David Quist published a report in *Nature* [25] presenting evidence that maize landraces, growing in remote regions in Mexico, were contaminated with transgenes, despite the fact that an official moratorium on growing GM maize has been imposed in the country.

This sparked off a concerted attack by pro-biotech scientists, allegedly orchestrated by Monsanto [26]. *Nature* withdrew support for that paper in February 2002, an act unprecedented in the whole history of scientific publication, for a paper that was neither wrong, nor challenged on its major conclusion. Subsequent research by Mexican scientists confirmed the finding, showing that the contamination was much more extensive than previously suspected [27]. Ninety-five percent of the sites sampled were contaminated, with degrees of contamination varying from 1% to 35%, averaging 10 to 15%. The companies involved have refused to provide molecular information or probes for research, which would sort out which are the liable parties for the damages caused. *Nature* refused to publish these confirmatory results.

Indeed, one main factor considered by the Innovest report (see above) that would damn Monsanto is the substantial investor losses that could arise from unintended transgenic contamination. Contamination is inevitable, the report states, and could bankrupt Monsanto and other biotech companies, leaving the rest of society to deal with the problem.

According to Ignacio Chapela, who finds himself caught up in the ensuing controversy with his University tenure still hanging in the balance, transgenic contamination in Mexico is still growing.

The extent of contamination of non-GM seeds is alarming. A spokesperson from Dow Agroscience was reported as saying that “the whole seed system is contaminated” in Canada [28]. Dr. Lyle Friesen of the University of Manitoba tested 33 certified seed stocks and found 32 contaminated. “Some contamination is so high you could raise a crop with it,” he said.

Tests on pollen flow found that wheat pollen will stay airborne for one hour at the minimum, which means it could be carried huge distances depending on the wind speed. Canola pollen is even lighter, and can remain airborne for 3 to 6 hours. A 35 mile/hour wind is not atypical, which “makes a real mockery of a separation distance of tens or even hundreds of metres”, said Percy Schmeiser, celebrated Canadian farmer who was ordered by the Canadian court to pay ‘damages’ to Monsanto, despite his claim that his neighbour's GM crop had contaminated his fields.

Organic farmers in Saskachewan have started legal proceedings against Monsanto and Aventis for contaminating their crops and ruining their organic status.

The European Commission ordered the study on the co-existence of GM and non-GM crops in May 2000 from the Institute for Prospective Technological Studies of the EU Joint Research Centre. The study was completed and delivered to the European Commission in January 2002, with the recommendation that it *not* be made public. The suppressed study, leaked to Greenpeace [29], confirmed what we already know: coexistence of GM farming and non-GM or organic farming would be impossible in many cases. Even in cases where it is technically feasible, it would require costly measures to avoid contamination and increase production costs for all farmers, especially small farmers.

Transgenic contamination is not limited to cross-pollination. New research shows that transgenic pollen, wind-blown and deposited elsewhere, or that has fallen directly to the ground, is a major source of transgenic contamination [30]. Such transgenic DNA was even found in fields where GM crops have never been grown, and soil samples contaminated with pollen was demonstrated to transfer transgenic DNA to soil bacteria (see later).

Why is contamination such a big issue? The immediate answer is that consumers are not accepting it. The more important reason is there are outstanding safety concerns.

Part 2: GM Crops Not Safe

Three

Science & Precaution

Precaution, common sense & science

We are told there is no scientific evidence that GM is harmful. But is it safe? That is the question we should ask. Where something can cause serious irreversible harm, it is right and proper for scientists to demand evidence demonstrating that *GM is safe beyond reasonable doubt*. That is usually dignified as 'the precautionary principle', but for scientists and for the public, it is just common sense [31-33].

Scientific evidence is no different from ordinary evidence, and should be understood and judged in the same way. Evidence from different sources and of different kinds has to be weighed and combined to guide policy decisions and actions. That's good science as well as good sense.

Genetic engineering involves recombining, i.e., joining together in new combinations, DNA from different sources, and inserting them into the genomes of organisms to make "genetically modified organisms", or "GMOs" [34].

GMOs are unnatural, not just because they have been produced in the laboratory, but because many of them can *only* be made in the laboratory, quite unlike what nature has produced in the course of billions of years of evolution.

Thus, it is possible to introduce new genes and gene products, many from bacteria, viruses and other species, or even genes made entirely in the laboratory, into crops, including food crops. We have never eaten these new genes and gene products, nor have they ever even been part of our food chain.

The artificial constructs are introduced into cells by invasive methods that result in random integration into the genome, giving rise to unpredictable, random effects, including gross abnormalities in animals and unexpected toxins and allergens in food crops. In other words, there is no possibility for quality control. This problem is compounded by the overwhelming instability of transgenic lines.

There are very few independent studies dedicated to the safety of

GM crops to health and the environment. Nevertheless, sufficient evidence has accumulated to indicate that GM crops are not safe.

Four

Safety Tests on GM Foods

Paucity of published data

There is a distinct scarcity of published data relevant to the safety of GM foods. Not only that, the scientific quality of what has been published is, in most instances, not up to the usually expected standards of good science.

In responding to the Scottish Parliament's recent investigation into the health impacts of GM crops [35], Stanley Ewen, histopathologist at Grampian University Hospital Trust, and leader of the Colorectal Cancer Screening Pilot in Grampian Region, summed up the situation,

"It is unfortunate that very few animal trials of GM human food are available in the public domain in scientific literature. It follows that GM foods have not been shown to be without risk and, indeed, the available scientific experimental results demonstrate cause for concern."

Two reports prior to 1999 revealed harmful effects on animals fed GM foods. The first was a report submitted to US Food and Drug Administration on Flavr Savr GM tomatoes fed to rats. Several of the rats developed erosions (early ulcers) of the lining of the stomach similar to those seen in the stomach of older humans on aspirin or similar medication. In humans, substantial life threatening haemorrhage may occur from these early ulcers.

The second paper, published in a peer-reviewed journal, was on feeding raw GM potatoes to month-old male mice. The results revealed proliferative growth in the lower small intestine [36].

The study by Pusztai and co-workers

No substantive studies on the health impacts on GM food had been carried out, until the then Scottish Office of Agriculture, Environment and Fisheries Department, SOAEFD funded the project headed by Pusztai at the Rowett Institute, to undertake a major investigation into the possible environmental and health hazards of GM-potatoes that had been transformed by British scientists using a gene taken from snowdrop bulbs [37].

The studies revealed that the two transgenic lines of GM-potatoes, which originated from the same transformation experiment, and were both resistant to aphid pests, *were not* substantially equivalent in composition to parent line potatoes, nor to each other. The crude, poorly defined and unscientific concept of “substantial equivalence” that regulators rely on in risk assessment has been criticised from its conception [38]. It has certainly outlived its usefulness.

More importantly, the results showed that diets containing GM potatoes had, in some instances, interfered with the growth of the young rats and the development of some of their vital organs, inducing changes in gut structure and function, and reducing their immune responsiveness to injurious antigens. In contrast, the animals fed on diets containing the parent, non-GM-potatoes or these potatoes supplemented with the gene product had no such effects. Some of the results have been published [39-42].

These findings have been attacked by many within the scientific establishment, but never disproved by repeating the work and publishing the results in peer-reviewed journals. The experiments by Pusztai and co-workers have clearly demonstrated that, in addition to possible toxicological studies, the safety of GM-foodstuffs must be established in short- and long-term feeding, metabolic and immune-response studies with *young* animals, as these are most vulnerable and the most likely to respond to, and show up any nutritional and metabolic stresses affecting development, a view shared by other scientists.

Multivariate statistical analysis of the results carried out independently by Scottish

Agricultural Statistics Service suggested that the major potentially harmful effects of the GM-potatoes were only in part caused by the presence of the snowdrop lectin transgene, and that the method of genetic transformation, and/or the disturbances in the potato genome also made major contributions to the changes observed.

Ewen and Pusztai’s paper, published in *The Lancet* [40] aroused much controversy, and it seems that attempts to discredit Pusztai by members of the Royal Society continue to this present day.

Ewen and Pusztai measured the part of the small bowel lining that produces new cells and found that the length of the new cell compartment had increased significantly in GM fed rats, but not in control rats fed non GM potatoes. The increased production of cells had to be due to a growth factor effect induced by the genetic modification within the potatoes.

Statistical analysis further revealed that the growth factor effect was not due to the expressed transgenic protein, the snowdrop lectin, but was the effect of the gene construct inserted into the DNA of the potato cell nucleus.

The construct includes not only the new gene, but also marker genes and a powerful promoter from the cauliflower mosaic virus (CaMV), which is at the centre of a major debate concerning its safety (see later).

Ewen [35] pointed out that although the whole and intact virus appears to be harmless, as we have been eating cauliflower type vegetables for millennia, "the use of the separate infectious part of the virus has not been tested in animals".

Further possible undesirable effects may involve the human liver's response to hepatitis virus, as the cauliflower mosaic virus and hepatitis B virus belong to the same family of pararetroviruses, with closely similar genomes and a distinctive life cycle.

That and other potential hazards of the CaMV promoter raised will be dealt with in more detail in a later chapter.

Five

Transgene Hazards

Bt toxins

The most obvious question on safety is with regard to the transgene and its product introduced into GM crops, as they are new to the ecosystem and to the food chain of animals and human beings.

The Bt toxins from *Bacillus thuringiensis*, incorporated in food and non-food crops, account for about 25% of all GM crops currently grown worldwide. It has been found to be harmful to mice, butterflies and lacewings up the food chain [24]. Bt toxins also act against insects in the Order of Coleoptera (beetles, weevils and styloplids), which contains some 28 600 species, far more than any other Order. Bt plants exude the toxin through the roots into the soil, with potentially large impacts on soil ecology and fertility.

Bt toxins may be actual and potential allergens for human beings. Some field workers exposed to Bt spray experienced allergic skin sensitization and produced IgE and IgG antibodies. A team of scientists have cautioned against releasing Bt crops for human use. They demonstrated that recombinant Cry1Ac protoxin from Bt is a potent systemic and mucosal immunogen, as potent as cholera toxin.

A Bt strain that caused severe human necrosis (tissue death) killed mice within 8 hours, from clinical toxic-shock syndrome. Both Bt protein and Bt potato harmed mice in feeding experiments, damaging their ileum (part of the small intestine). The mice showed abnormal mitochondria, with signs of degeneration and disrupted microvilli (microscopic projections on the cell surface) at the surface lining the gut.

Because Bt or *Bacillus thuringiensis* and *Bacillus anthracis* (anthrax species used in biological weapons) are closely related to each other and to a third bacterium, *Bacillus cereus*, a common soil bacterium that causes food poisoning, they can readily exchange plasmids (circular DNA molecules containing genetic origins of replication that allow replication independent of the chromosome) carrying toxin genes. If *B. anthracis* picked up Bt genes from Bt crops by horizontal gene transfer (see later), new strains of *B. anthracis* with unpredictable properties could arise.

‘Pharm’ crops

Other hazardous genes and bacterial and viral sequences are incorporated into our food and non-food crops as vaccines and pharmaceuticals in ‘next generation’ GM crops [43, 44]. These pharm crops include those expressing cytokines, known to suppress the immune system, induce sickness and central nervous system toxicity, as well as interferon alpha, which is reported to cause dementia, neurotoxicity and mood and cognitive side effects. Some contain viral sequences such as the ‘spike’ protein gene of the pig coronavirus, in the same family as the SARS virus blamed for the current epidemic [45, 46].

The glycoprotein gene *gp120* of the AIDS virus HIV-1, incorporated into GM maize as a 'cheap, edible oral vaccine', is yet another biological time-bomb. There is a lot of evidence that this gene can interfere with the immune system, as it has homology to the antigen-binding variable regions of the immunoglobulins, and has recombination sites similar to those of the immunoglobulins. Furthermore, these recombination sites are also similar to the recombination sites present in many viruses and bacteria, with which the *gp120* can recombine to generate deadly pathogens [47-49].

Bacterial and viral DNA

A hitherto neglected source of hazard - in GM crops, though not in gene therapy where it is recognized as something to avoid - is the DNA from bacteria and their viruses, which have a high frequency of the CpG dinucleotide [21]. These CpG motifs are immunogenic and can cause inflammation, septic arthritis and promotion of B cell lymphoma. Yet many genes introduced into GMOs are from bacteria and their viruses, and these pose other risks as well (see below).

Six

Terminator Crops Spread Male Sterility

'Suicide' genes for sterility

In the interest of avoiding tedious semantic arguments, ‘terminator crops’ here refer to any transgenic crop engineered with a ‘suicide’ gene for male, female or seed sterility, for the purpose of preventing farmers from saving and replanting seeds, or protecting patented traits.

The public first became aware of terminator technology in patents jointly owned by US Department of Agriculture and Delta and Pine Land Company. There were massive protests worldwide, and Monsanto, which acquired the Delta and Pine patent rights, backed down from developing the terminator crops *described in that particular patent*. However, as Ho and Cummins were to learn, there are many ways to engineer sterility, each the subject of a separate patent.

It transpired that terminator crops have been field tested in Europe, Canada and the US since the early 1990s, and several were already commercially released in North America [50]. The GM oilseed rape, both spring and winter varieties, that form the main part of the Farm Scale Evaluations in the United Kingdom are engineered to be male sterile.

GM oilseed rapes are terminator crops

The male sterility system in these GM oilseed rapes consists of three lines.

The *male sterile line* is maintained in a 'hemizygous' state, i.e., with only one copy of the ‘suicide’ gene, barnase, joined to a glufosinate-tolerance gene. The *barnase* gene is driven from a promoter (gene switch) that's active only in the anther or male part of the flower. The expression of the *barnase* gene in the anther gives rise to the protein barnase, an RNAse (enzyme that breaks down RNA), which is a potent cell poison. The cell dies and stops anther development, so no pollen is produced. This male sterile line is perpetrated in the hemizygous state by crossing to a non-GM variety, and using glufosinate-ammonium to kill off half the plants in the offspring generation that do not have a copy of the *H-barnase* transgene joined to it.

The *male restorer line* is homozygous (with two copies) for the ‘sterility-restorer’ gene, *barstar*, also joined to glufosinate-tolerance gene *H*. The *barstar* gene too, is placed under the control of the special promoter that’s active in the anther. Its expression gives the barstar protein that's a specific inhibitor of barnase, thereby neutralising the latter’s activity.

Crossing the male-sterile line to the male-restorer line produces a F1 hybrid, in which the barnase is neutralised by barstar, thus restoring anther development to produce pollen.

It can be shown that the *F1 hybrid* actually spreads both the herbicide tolerance gene and the suicide gene for male sterility in its pollen, with potentially devastating impacts on both agricultural and natural biodiversity. It makes a mockery of the UK and US government's promotion of these plants as a way to ‘contain’ or ‘prevent’ the spread of transgenes. The real purpose of this kind of terminator engineering is to protect corporate patents.

Seven

Herbicide Hazards

Herbicide profits

More than 75% of all GM crops currently grown are engineered to be tolerant to broad-spectrum herbicides manufactured by the same companies that make most of their profits from the sales of the herbicides. These broad-spectrum herbicides not only kill plants indiscriminately, they are also harmful to practically all species of animal wildlife and to human beings.

Glufosinate ammonium

Glufosinate ammonium or phosphinothricin, is linked to neurological, respiratory, gastrointestinal and haematological toxicities as well as birth defects in humans and mammals [51]. It is toxic to butterflies and a number of beneficial insects, also to the larvae of clams and oysters, *Daphnia* and some freshwater fish, especially the rainbow trout. It inhibits beneficial soil bacteria and fungi, especially those that fix nitrogen.

The loss of insects and plants would have knock-on effects on birds and small animal life.

In addition, some plant pathogens were found to be highly resistant to glufosinate while organisms antagonistic to those pathogens were seriously and adversely affected. This could have catastrophic impacts on agriculture.

The glufosinate tolerant plants contain the *pat* (phosphinothricin acetyl transferase) gene, which inactivates phosphinothricin by adding an acetyl group to it, to make acetylphosphinothricin. The latter accumulates in the GM plant, and is a completely new metabolite in the crop, as well as for the entire food chain leading up to human beings, the risks of which have not been considered.

Data supplied by AgrEvo, which became Aventis and now Bayer CropScience, show that micro-organisms in the gut of warm-blooded animals can remove the acetyl group and regenerate the toxic herbicide. Phosphinothricin inhibits the enzyme glutamine synthetase, which converts the essential amino acid, glutamic acid to glutamine. The net result of the action of glufosinate is that ammonia and glutamate accumulate whilst glutamine is limited. It is the accumulation of ammonia that is the lethal action in plants.

In mammals, the consequences of inhibition of glutamine synthetase are more associated with the increased levels of glutamate, and decreased levels of glutamine. Circulating ammonia is removed in the liver by the urea cycle. However, the brain is highly sensitive to the toxic effects of ammonia and the removal of excess ammonia depends on its incorporation into glutamine. Glutamate is a major neurotransmitter, and such large disturbance to its metabolism is bound to impact on health.

These known effects are sufficient to halt all field trials of GM crops immediately, until critical questions about the metabolism, storage and reconversion of the N-acetylphosphinothricin have been fully answered for *all pat* gene-containing products.

Glyphosate

The other major herbicide used in conjunction with GM crops, glyphosate (Round-up), is no better [52]. Glyphosate kills plants by inhibiting the enzyme, 5-enolpyruvylshikimate-3-phosphate synthetase (EPSPS), which is critical for the biosynthesis of aromatic amino acids such as phenylalanine, tyrosine and tryptophan, vitamins, and many secondary metabolites. The shikimate pathway functions in the chloroplasts of green plants. The killing action of the herbicide requires that the plant be growing and exposed to light.

GM crops modified to be tolerant to glyphosate are called “Round-up ready”. They are modified with two main genes. One gene imparts reduced sensitivity to glyphosate and the other expresses an enzyme that enables the plant to degrade glyphosate. The expression of both genes is directed to the chloroplasts, the site of the herbicide activity, by adding the coding sequences of a plant-derived 'transit peptide'.

The first gene expresses a bacteria-derived version of the plant enzyme involved in the shikimate biochemical pathway for the production of the aromatic amino acids. The plant version of this enzyme is sensitive to glyphosate, leading to suppression of growth or death of the plant. However, the bacteria-derived version of this enzyme is insensitive to glyphosate, thereby fulfilling the aromatic amino acid requirements of the plant. The second gene, also bacterial, expresses an enzyme that degrades glyphosate. The coding sequence of this gene was altered to enhance the degradation glyphosate.

The impacts of glyphosate on humans and other animals have been controversial since the registration of the pesticide. Regulatory agencies worldwide have been reluctant to deal with findings that suggested the pesticide posed an unacceptable threat to health and the environment. But these have been amply confirmed.

A recent paper reported that Round-up provoked cell division dysfunction; the authors pointed out that human cancers are associated with defects in cell cycle transitions, and questioned the safety of glyphosate and Round-up for human health. Round-up was found to inhibit the synthesis of steroids by disrupting acute regulatory protein expression. Many environmental toxins have been found to disrupt steroid hormone function leading to sexual dysfunction and reproductive failure. An epidemiological study of the effect of pesticide exposure on spontaneous abortion in Ontario farming populations showed that glyphosate exposure nearly doubled the risk of late spontaneous abortion.

Round-up exposure caused DNA adducts to appear in mice. Such DNA adducts are associated with gene and chromosome damage leading to cancer. Bovine lymphocytes exposed to glyphosate showed chromosome aberrations indicating that the herbicide was genotoxic. Glyphosate disrupted the enzymatic patterns of pregnant rats and their fetuses.

Round-up is also genotoxic for fish and frogs. Glyphosate produced polyembryony in water snails, leading to larger snail populations, and hence larger populations of the snail parasite *Fasciola hepatica* that causes fascoliasis in humans and other vertebrates. Field dose exposure of earthworms caused at least 50 percent mortality and significant intestinal damage among surviving worms.

The nitrogen fixation symbiont in GM and unmodified soya is sensitive to glyphosate, and early application of glyphosate led to decreased crop biomass and nitrogen. Glyphosate application at elevated temperature (the frequent temperature of 35 C during early summer) to the Round-up Ready soya crop led to meristem damage related to increased transport of the herbicide to the meristem.

Glyphosate application in conventional weed control led to destruction and local extinction of endangered plant species. In forest ecosystems, bryophytes and lichens were significantly reduced by glyphosate application. Glyphosate treatment of bean seedlings led to short-term increases in dampening-off pathogen in treated soil.

Glyphosate application to control invasive species along tidal flats gave unexpected secondary effects. After spraying, the herbicide in sediment declined 88% while in the target perennial grass the herbicide increased 591%, and was stored in rhizomes of the grasses. Glyphosate persists in soil and groundwater and was observed in well water in sites adjacent to sprayed areas.

There is a wealth of published scientific studies showing that the massive increase in use of glyphosate in conjunction with GM crops poses significant threat to human and animal health and to the environment. It will result in the loss of endangered species and an extensive remodeling of the ecosystem. And human beings will be poisoned without their knowledge and consent.

Eight

Horizontal Gene Transfer

Horizontal gene transfer & epidemics

Horizontal gene transfer, the direct transfer of genetic material into the genomes of organisms, whether of the same or totally unrelated species, is by far the most serious safety issue that's unique to genetic engineering [53].

The world has been whipped up into hysteria over terrorist attacks and 'weapons of mass destruction' since September 11, 2001. Governments want to ban publication of sensitive scientific research results, and a group of major life sciences editors and authors has concurred. Some scientists even suggest an international body to police research and publication [46]. But few have acknowledged that genetic engineering itself is inherently dangerous, as first pointed out by the pioneers of genetic engineering themselves in the Asilomar Declaration in the mid 1970s, and as some of us have been reminding the public and policy-makers more recently [54, 55].

But what caught the attention of the mainstream media was the report in January 2001 of how researchers in Australia ‘accidentally’ created a deadly virus that killed all its mouse victims in the course of manipulating a harmless virus. “Disaster in the making: An engineered mouse virus leaves us one step away from the ultimate bioweapon”, was the headline in the *New Scientist* article. The editorial showed even less restraint: “The genie is out, biotech has just sprung a nasty surprise. Next time, it could be catastrophic.”

That, and the current SARS epidemic remind us that horizontal gene transfer and recombination create new viruses and bacteria that cause diseases, and if genetic engineering does anything, it is to greatly enhance the scope and tendency for horizontal gene transfer and recombination.

Genetic engineering enhances the scope and tendency for horizontal gene transfer

In the first place, genetic engineering involves the rampant recombination of genetic material from widely diverse sources that would otherwise have very little opportunity to mix and recombine in nature. Some newer techniques, for example, ‘DNA shuffling’ [56, 57] will create in the matter of minutes millions of new recombinants in the laboratory that have never existed in billions of years of evolution. There is no limit to the sources of DNA that can be shuffled in this way.

In the second place, disease-causing viruses and bacteria and their genetic material are the predominant materials and tools of genetic engineering, as much as for the intentional creation of bio-weapons. And this includes antibiotic resistance genes that make infections more difficult to treat.

And finally, the artificial constructs created by genetic engineering are designed to cross species barriers and to jump into genomes, i.e., to further enhance and speed up horizontal gene transfer and recombination, now acknowledged to be the major route to creating new disease agents, possibly much more important than point mutations which change isolated bases in the DNA.

Add to that the inherent instability of transgenic DNA mentioned earlier, which makes it more likely to break and recombine, and we begin to realise why we don't need bio-terrorists when we have genetic engineers.

Nine

The CaMV 35S Promoter

‘Recombination hotspot’

Some transgenic constructs are less stable than others, such as those containing the cauliflower mosaic virus (CaMV) 35S promoter.

The CaMV infects plants of the cabbage family. One of its promoters, the 35S promoter, has been widely used in GM crops since the beginning of plant genetic engineering, before some of its worrying features came to light. The most serious is its possession of a ‘recombination hotspot’, where it tends to recombine with other DNA; although definitive evidence for that did not appear until much later.

Since the early 1990s, major doubts have arisen over the safety of viral genes incorporated into GM crops to make crops resistant to viral attack. Many of the viral genes tended to recombine with other viruses to generate new and at times super-infectious viruses.

In 1999, definitive evidence for the recombination hotspot in the CaMV 35S promoter came from work published independently by two research groups. This was highly significant in view of the findings of Ewen and Pusztai reviewed earlier, suggesting that the damage to young rats fed GM potatoes could be due to the transformation process itself or to the transgenic construct.

Ho *et al* reviewed the safety implications of the CaMV 35S promoter, pointing out that its recombination hotspot is flanked by multiple motifs known to be involved in recombination, which are similar to other recombination hotspots, including the borders of the *Agrobacterium T DNA* vector most frequently used in making transgenic plants. The suspected mechanism of recombination - double-stranded DNA breaks followed by repair - requires little or no DNA sequence homologies, and recombination between viral transgenes and infecting viruses has been amply demonstrated. In addition, the CaMV 35S promoter functions efficiently in all plants, as well as green algae, yeast and *E. coli*. It has a modular structure, with parts common to, and interchangeable with promoters of many other plant and animal viruses.

These findings suggested that transgenic constructs with the

CaMV 35S promoter might be especially unstable and prone to horizontal gene transfer and recombination, with all the attendant hazards: gene mutations due to random insertion, cancer, reactivation of dormant viruses and generation of new viruses, some of which could account for the observations described by Ewen and Pusztai [35, 37, 40].

When the paper [58] was accepted for publication, the Journal, *Microbial Ecology in Health and Disease*, put out a press release on its website, labelling it ‘hot topic’. Within a day, someone by the name of Klaus Amman appeared to have organised at least nine critiques that rebounded around the Internet, ranging from the abusive and condescending to the relatively moderate. It later transpired that Klaus Amman is a key player in establishing (or, as we perceive, undermining) biosafety standards on the international scene, and holds many posts in organisations funded by the biotech industry.

Ho *et al* answered all the criticisms in a paper that was circulated on the Internet, and subsequently published in the scientific journal. The critics have failed to respond to this day.

Unfortunately, the most outrageous and abusive remarks were incorporated into one ‘analysis’ piece written by an editor of *Nature biotechnology* under “Business and regulatory news” [59]. That ‘analysis’, concocted entirely of hearsay and opinions, contained such defamatory, libellous statements that the journal had to give Ho *et al* a right to reply when challenged. The reply was eventually published several months later [60], along with the editor's ‘apology’ that he had failed to cite their rebuttal, but was actually another attack on them. This time, *Nature biotechnology* refused to let them reply.

All of the substantive scientific criticisms eventually turned up in a paper published in the journal where the original paper appeared, co-authored by Roger Hull and Phil Dale, a member of the UK Advisory Committee on Novel Foods and Processes (ACNFP) [61]. Their main criticisms boiled down to the following.

First, people have been eating the virus in infected cabbages and cauliflower for many years without harm, so why should they worry about the CaMV 35S promoter? Second, plants are already loaded with pararetroviral sequences, not unlike CaMV, so why should there be any risks?

The criticisms were thoroughly rebutted in a paper that was longer than the original, which appeared in the same journal soon afterwards

[62]. And no further response followed. In fact, critics were careful never to mention the rebuttal.

It was pointed out, among other things, that people have *not* been eating CaMV 35S promoter plucked from its natural genetic and evolutionary context and incorporated into transgenic DNA.

The fact that plants are "loaded" with pararetroviral sequences similar to CaMV and other potentially mobile elements can only make things worse. Pararetroviruses are viruses that use reverse transcriptase, but do not depend on integrating into the host genome for replication. Pararetroviruses include a family that contains the human pathogen, hepatitis B virus. The CaMV 35S promoter could activate dormant viruses like hepatitis B, which was also known to have integrated into some human genomes, and appeared to be associated with the disease.

Most, if not all of the elements integrated into the genome would have been 'tamed' in the course of evolution and hence are no longer mobile. But integration of transgenic constructs containing the 35S promoter may mobilize the elements. The elements may in turn provide helper-functions to destabilize the transgenic DNA, and may also serve as substrates for recombination to generate more exotic invasive elements.

Evidence has emerged, since, that integration of foreign genes into the genome associated with the genetic modification can indeed activate transposons and proviral sequences, leading to destabilisation of the genome [63]. So Ho *et al* were not wide off the mark.

In the course of debating with the critics, Ho and co-workers found even more damning evidence [64]. It turns out that although the CaMV virus infects only plants in the cabbage family, its 35S promoter is promiscuously active in species across the living world, not just bacteria, algae, fungi, and plants, but also animal and human cells, as they discovered in a scientific paper dating back to 1990. Plant geneticists who have incorporated the CaMV 35S promoter into practically all GM crops now grown commercially were apparently unaware of that, and are still not admitting to it in public.

The UK Advisory Committee on Releases to the Environment (ACRE) has no excuse for omitting the information in its latest Report [65] reiterating "no evidence of harm", as Mae-Wan Ho has drawn attention to it many times, both in written submissions and in oral evidence presented at several open hearings. Behind the scenes, however, the CaMV 35S promoter has been quietly withdrawn. It no longer appears in most of the GM crops under development.

The controversy surrounding the transgenic contamination of Mexican landraces is not so much that the contamination had occurred, rather, it is the possibility that, because the transgenic constructs were unstable, they could be [26], according to a critic, “fragmenting and promiscuously scattering throughout genomes.” All the transgenic maize constructs that might have been responsible for the contamination contained the CaMV 35S promoter, which was why the promoter could be used to test for transgenic contamination. Such fragmentation and scattering of unstable DNA throughout the genome are known to activate dormant proviruses and transposons (see above), causing DNA rearrangements, deletions, translocations and other disturbances, which could destabilise the genomes of the landraces, driving the landraces towards extinction.

Ten

Transgenic DNA More Likely to Spread

Transgenic DNA versus natural DNA

Transgenic DNA is different from natural DNA in many respects, all of which contribute to its increased propensity for horizontal transfer into genomes of unrelated organisms, where it may also recombine with new genes Box 1 [53].

Box 1

Transgenic DNA more likely to spread horizontally

- Transgenic DNA often contains new combinations of genetic material that have never existed.
- Transgenic DNA has been designed to jump into genomes.
- The unnatural gene constructs tend to be structurally unstable and hence prone to break and join up or recombine with other genes.
- The mechanisms that enable foreign gene constructs to jump into the genome enable them to jump out again and reinsert at another site or in another genome. For example, the enzyme integrase, which catalyzes the insertion of viral DNA into the host genome, also functions as a disintegrase, catalyzing the reverse reaction. These integrases belong to a superfamily of similar enzymes that are present in all genomes, from viruses and bacteria to higher plants and animals. Recombinases of transposons are similar.
- The borders of the most commonly used vector for transgenic plants, the T-DNA of Agrobacterium, are recombination hotspots (sites that tend to break and join). In addition, a recombination hotspot is also associated with the cauliflower mosaic virus (CaMV) promoter and many terminators (genetic signals for ending transcription), which means that the whole or parts of the integrated DNA will have an increased propensity for secondary horizontal gene transfer and recombination.

- Recent evidence indicates that foreign gene constructs tend to integrate at recombination hotspots in the genome, which again, would tend to increase the chances of transgenic DNA disintegrating and transferring horizontally.
- Transgenic DNA often has other genetic signals, such as origins of replication left over from the plasmid vector. These are also recombination hotspots, and in addition, can enable the transgenic DNA to be replicated independently as a plasmid that's readily transferred horizontally among bacteria.
- The metabolic stress on the host organism due to the continuous over-expression of the foreign genes linked to aggressive promoters such as the CaMV 35S promoter will also increase the instability of the transgenic DNA, thereby facilitating horizontal gene transfer.
- Transgenic DNA is typically a mosaic of DNA sequences from many different species and their genetic parasites; these homologies mean that it will be more prone to recombine with, and successfully transfer to, the genomes of many species as well as their genetic parasites. Homologous recombination typically occurs at one thousand to one million times the frequency of non-homologous recombination.

Evidence that transgenic DNA is different

There has been only one experiment ever carried out to test the hypothesis that transgenes are the same (or not) as mutants induced by conventional means (mutagenesis), such as exposure to X-rays and chemical mutagens, which cause changes in the base sequence of DNA.

Bergelson and colleagues [66] obtained a mutant for herbicide-tolerance by conventional mutagenesis in a laboratory strain of *Arabidopsis*, and created transgenic lines by introducing the mutant gene, spliced into a vector, into host plant cells.

They then compared the rate at which transgenic and non-transgenic mutant plants spread the herbicide-tolerance trait to normal, wild type plants grown nearby. They found that the transgenes from the transgenic plants were up to 30 times more likely to escape and spread than the same gene obtained by mutagenesis.

The results are difficult to explain in terms of ordinary cross-pollination. Was it because introducing the transgene by means of a vector led to all kinds of unexpected effects? Did the transgenic plants produce more pollen, or more viable pollen? Was the pollen from transgenic plants more attractive to bees?

Another possibility for the increased spread of transgenes is horizontal gene transfer, via insects visiting the plants for pollen and nectar, or simply feeding on the sap or other parts of successive transgenic and wild type plants. Bergelson said they had no evidence for horizontal gene transfer, but could not rule it out. But they have not gone on to investigate that possibility.

Regardless of the manner in which the transgenes had spread, the experiment did demonstrate that transgenic DNA does not behave in the same way as non-transgenic DNA.

Eleven

Horizontal Transfer of Transgenic DNA

Experiments demonstrating horizontal transfer of transgenic DNA

Horizontal transfer of transgenes and antibiotic-resistant marker genes from genetically engineered crop plants into soil bacteria and fungi had been demonstrated in the laboratory by the mid 1990s. Transfer of transgenes to fungi was achieved simply by growing the fungi with the GM plant, and transfer to bacteria achieved by applying total DNA from the GM plant to cultures of bacteria.

By the late 1990s, successful transfers of a kanamycin-resistance marker gene to the soil bacterium *Acinetobacter* were obtained with total DNA extracted from homogenized leaves in a range of transgenic plants [67]: *Solanum tuberosum* (potato), *Nicotiana tabacum* (tobacco), *Beta vulgaris* (sugar beet), *Brassica napus* (oil-seed rape), and *Lycopersicon esculentum* (tomato). It was estimated that about 2 500 copies of the kanamycin-resistance genes (from the same number of plant cells) was sufficient to successfully transform one bacterium, despite the fact that there was a 6 ´ 10^6-fold excess of plant DNA present. Positive results of horizontal gene transfer in this system were obtained even with just 100 microlitres of ground up plant leaf added to the bacteria.

Obfuscation & misrepresentation

But from the beginning, obfuscation and misrepresentation reigned supreme. Despite the misleading title in a paper by Schluter, Futterer and Potrykus, which states that horizontal gene transfer in their experiment "occurs, if at all, at an extremely low-frequency"[68], the data demonstrated a high frequency of gene transfer of 5.8 x 10^{-2} per recipient bacterium under optimum conditions.

But the authors then proceeded to calculate a theoretical gene transfer frequency of 2.0 x 10^{-17}, or close to zero, under extrapolated "natural conditions". That, they have done by assuming that different factors acted independently, and by inventing the 'natural conditions', which are largely unknown and unpredictable, and, by the authors' own admission, synergistic effects from combinations of factors cannot be ruled out.

This paper was subsequently widely cited as showing that horizontal gene transfer does not happen.

Field experiment provides *prima facie* evidence

In 1999, researchers in Germany [69] had already reported the first, and still only, field-monitoring experiment in the world, that provided prima facie evidence that transgenic DNA had transferred from the GM sugar beet plant debris to bacteria in the soil. Mae-Wan Ho circulated a detailed review of this evidence, and duly submitted it to the UK government's science advisors. They dismissed that evidence, and worse, cited it as evidence that horizontal gene transfer did not occur.

DNA not only persists in the external environment, both in the soil and in water; it is not broken down sufficiently quickly in the digestive system to prevent transgenic DNA transferring to microorganisms resident in the gut of animals.

Transgenic DNA transfer in the mouth

Such transfer could start in the mouth. Mercer *et al* reported in 1999 [70] that a genetically engineered plasmid had a 6 to 25% chance of surviving intact after 60 minutes of exposure to human saliva. Moreover, the partially degraded plasmid DNA was capable of transforming *Streptococcus gordonii*, one of the bacteria that normally live in the human mouth and pharynx. The frequency of transformation dropped exponentially with time, but it was still significant after 10 minutes. Human saliva actually contains factors that promote transformation in bacteria resident in the mouth.

This research was done in the test-tube, and the authors clearly stated that, "further investigations are needed to establish whether transformation of oral bacteria can occur at significant frequencies *in vivo*." However, no such studies have been carried out since, which is difficult to understand, *as the original research was commissioned by the UK government, as part of the Novel Foods Programme*.

Another group in Leeds University, however, got a grant from the then newly established Food Standards Agency to investigate the possibility of horizontal gene transfer in the stomachs of ruminants [71], where food remains for long periods of time. The researchers found that transgenic DNA was rapidly broken down in the fluids from the rumen and the silage, but that nevertheless, horizontal transfer could take place before the transgenic DNA was completely degraded.

They also found that transgenic DNA was very slow to break down in saliva, and therefore, the mouth could be a major site for horizontal gene transfer. This confirmed the results obtained by Mercer *et al* [70]. But once again, no follow up work was done in live animals. Was it a case of avoiding doing the obvious experiments for fear of finding positive results that would be more difficult to dismiss?

Transfer of transgenic DNA through the wall of the intestine & the placenta

There's more to the scope of horizontal gene transfer as revealed in the existing scientific literature. Döerfler's group in Germany have carried out a series of experiments on the fate of foreign DNA in food, beginning in the early 1990s.

They fed mice DNA, either isolated from the bacteria virus M13, or as the cloned gene for the green fluorescent protein inserted into a plasmid. They found that a small, albeit significant percentage of the viral and plasmid DNA not only escaped complete degradation in the gut, but could pass through the wall of the intestine into the blood stream, to get into some white blood cells, spleen and liver cells, and become incorporated into the mouse cell genome [72]. When fed to pregnant mice, the foreign DNA could be found in some cells of the foetuses and the newborn animals, showing that it had gone through the placenta [73].

This work underlines the hazards of all kinds of naked DNA, including viral genomes, created by the genetic engineering industry, that Norwegian virologist and science advisor to the Norwegian government, Terje Traavik [74] and others [54, 55] have drawn attention to.

In a paper published in 1998, Döerfler and Schubbert stated [73], “The consequences of foreign DNA uptake for mutagenesis [generating mutations] and oncogenesis [causing cancer] have not yet been investigated”. The relevance of this remark is striking with regard to the cancer cases identified among the recipients of gene therapy in the latter part of 2002 [75]. It makes the point that exposures to transgenic DNA carry the same risks, regardless of whether it is from gene therapy or from GM foods. Gene therapy is just the genetic modification of human beings, and uses constructs very similar to those for the genetic modification of plants and animals.

Avoidance of definitive experiments

In a report published in 2001 [76], the fate of ordinary soybean DNA from soybean leaves was compared with that of transgenic plasmid DNA. It confirmed earlier findings. Transgenic plasmid DNA invaded the cells of many tissues.

But like most of the research projects reviewed, this one too, seemed to have stopped short of attempting to obtain clearer, definitive results, which could easily have been done by feeding mice transgenic soya, and monitoring for the fate of both the transgenic DNA and the plant's own DNA. That would have gone some way to settle the issue Ho and Cummins have repeatedly raised: that transgenic DNA may be more invasive of cells and genomes than natural DNA.

Indeed, as Ewen points out [35], the possibility cannot be excluded that feeding GM products such as maize to animals also carries risks. Cow’s milk may contain GM derivatives and even a fillet steak may contain active GM material, as DNA is extraordinarily stable, and is often not destroyed by heat. DNA has even been recovered recently from soil sediments 300 000 to 400 000 years old [77]. The lead researcher Professor Alan Cooper of Oxford University, in his recent visit to New Zealand, is reported to have said [78], “The ability of DNA to persist in soils for so long was completely underestimated . . . and illustrates how little we know,” and “a great deal more research is needed before we could predict the effect of releasing GE plants.”

Transfer of transgenic DNA in food to bacteria in human gut

The UK government eventually commissioned research to look for horizontal gene transfer into bacteria in the gut of human volunteers *and found positive results*. But once again, the findings were dismissed and downplayed, all the more scandalous as the experiment was already designed to *bias against* detecting horizontal gene transfer in the first place.

The research in question is the final part of the UK Food Standards Agency (FSA) project on evaluating the risks of GMOs in human foods [79].

Transgenic DNA transferring to bacteria in the human gut is not at all unexpected. We already know that DNA persists in the gut, and that bacteria can readily take up foreign DNA, from previous research reviewed here. Why had our regulators waited so long to commission the research? And when they did, the scientists appeared to have designed the experiment so as to stack the odds heavily against finding a positive result [80].

For example, the method for detecting transgenic DNA depended on amplifying a small part - 180bp - of the entire transgenic DNA insert that was at least ten or twenty times as long. So, any other fragment of the insert would not be detected, nor would a fragment that did not overlap the whole 180bp amplified, or that had been rearranged. The chance of obtaining a positive result is 5% at best, and likely to be much, much less. *Thus, a negative finding with this detection method most probably would not indicate the absence of transgenic DNA*.

Despite that, they still found a positive result, which the UK Food Standards Agency immediately dismissed and obfuscated.

Agrobacterium vector a vehicle for gene escape

That is not all. Recent evidence strongly suggests that the most common method of creating transgenic plants may also serve as a ready route for horizontal gene transfer [81, 82].

Agrobacterium tumefaciens, the soil bacterium that causes crown gall disease, has been developed as a major gene transfer vector for making transgenic plants. Foreign genes are typically spliced into the *T-DNA* - part of a plasmid of *A. tumefaciens* called Ti (tumour-inducing) - which ends up integrated into the genome of the plant cell that subsequently develops into a tumour. That much was known, at least since 1980.

But further investigations revealed that the process whereby *Agrobacterium* injects *T-DNA* into plant cells strongly resembles *conjugation*, or mating between bacterial cells.

Conjugation, mediated by certain bacterial plasmids, requires a sequence called the origin of transfer (*oriT*) on the DNA that's transferred. All the other functions can be supplied from unlinked sources, referred to as 'trans-acting functions' (or *tra*). Thus, 'disabled' plasmids, with no trans-acting functions, can nevertheless be transferred by 'helper' plasmids that carry genes coding for the trans-acting functions. And that's the basis of a complicated vector system devised, involving *Agrobacterium T-DNA*, which has been used for creating numerous transgenic plants.

But it soon transpired that the left and right borders of the *T-DNA* are similar to *oriT*, and can be replaced by it. Furthermore, the disarmed *T-DNA*, lacking the trans-acting functions (*virulence* genes that contribute to disease), can be helped by similar genes belonging to many other pathogenic bacteria. It seems that the trans-kingdom gene transfer of *Agrobacterium* and the conjugative systems of bacteria are both involved in transporting macromolecules, not just DNA but also protein.

That means transgenic plants created by the *T-DNA* vector system have a ready route for horizontal gene escape, via *Agrobacterium*, helped by the ordinary conjugative mechanisms of many other bacteria that cause diseases, which are present in the environment.

In fact, the possibility that *Agrobacterium* can serve as a vehicle for horizontal gene escape was first raised in 1997 in a study sponsored by the UK Government [83], which reported it was extremely difficult to get rid of the *Agrobacterium* in the vector system after transformation. Treatment with an armoury of antibiotics and repeated subculture over 13 months failed to get rid of the bacterium. Furthermore, 12.5% of the *Agrobacterium* remaining still contained the binary vector (T-DNA and helper plasmid), and *were hence fully capable of transforming other plants*. This research was later published in a scientific journal [84].

Several other observations make gene escape via *Agrobacterium* even more likely. *Agrobacterium* not only transfers genes into plant cells; there is possibility for *retro*transfer of DNA *from* the plant cell *to Agrobacterium* [85].

High rates of gene transfer are associated with the plant root system and the germinating seed, where conjugation is most likely [86]. There, Agrobacterium could multiply and transfer transgenic DNA to other bacteria, as well as to the next crop to be planted. These possibilities have yet to be investigated empirically.

Finally, *Agrobacterium* attaches to and genetically transforms several human cell lines [87]. In stably transformed HeLa cells (a human cell line derived originally from a cancer patient), the integration of *T-DNA* occurred at the right border, exactly as would happen when it is transferred into a plant cell genome. This suggests that *Agrobacterium* transforms human cells by a mechanism similar to that which it uses for transforming plants cells.

Twelve

Hazards of Horizontal Gene Transfer

A summary

As is clear from the past chapters, the hazards that could arise from the horizontal transfer of transgenic DNA are unique to genetic engineering, and are summarised in Box 2.

Box 2

Potential hazards of horizontal gene transfer from genetic engineering

- Generation of new cross-species viruses that cause disease
- Generation of new bacteria that cause disease
- Spread of drug- and antibiotic-resistance genes among the viral and bacterial pathogens, making infections untreatable
- Random insertion into genomes of cells, resulting in harmful effects including cancer
- Reactivation and recombination with dormant viruses (present in all genomes) to generate infectious viruses
- Spread of dangerous new genes and gene constructs that have never existed
- Multiplication of ecological impacts due to all of the above.

Experiments that appear to have been avoided so far

These critiques have been communicated to ACRE and ACNFP, together with a series of obvious experiments that the Food Standards Agency should commission, in a paper tabled at an open meeting organised by ACNFP [88]. These are described in a slightly revised form in Box.3.

Box 3

Missing experiments on the safety of GM food and crops

The following are some definitive experiments that would inform on the safety of GM food and crops. They seem to have been intentionally avoided so far.

1. Feeding experiments similar to those carried out by Pusztai's team, using well-characterized transgenic soya and/or maize meal feed, with appropriate, unbiased monitoring for transgenic DNA in the faeces, blood and blood cells, and post-mortem histological examinations that include tracking transfer of transgenic DNA into the genome of cells. As an added control, non-transgenic DNA from the same GM feed sample should also be monitored.
2. Feeding trials on human volunteers using well-characterized transgenic soya and/or maize meal feed, with appropriate, unbiased monitoring for transgenic DNA and horizontal gene transfer in the mouth and in the faeces, blood and blood cells. As an added control, non-transgenic DNA from the same GM feed sample should also be monitored.
3. Investigation on the stability of transgenic plants in successive generations of growth, especially those containing the CaMV 35S promoter, using appropriate quantitative molecular techniques.
4. Full molecular characterisation of all transgenic lines to establish uniformity and genetic stability of the transgenic DNA insert(s), and comparison with the original data supplied by the biotech company to gain approval for field trials or for commercial release.
5. Tests on all transgenic plants created by the *Agrobacterium T-DNA* vector system for the persistence of the bacteria and the vectors. The soil in which the transgenic plants have been grown should be monitored for gene escape to soil bacteria. The potential for horizontal gene transfer to the next crop via the germinating seed and root system should be carefully monitored.

Thirteen

Conclusion to Parts 1 & 2

Our extensive review of the evidence has convinced us that GM crops are neither needed nor wanted, that they have failed to deliver their promises and instead are posing escalating problems on the farm. Furthermore, they are by no means safe. Consequently they should be firmly rejected as a viable option for the future of agriculture.

Part 3. The Manifold Benefits of Sustainable Agriculture

Fourteen

Why Sustainable Agriculture?

Modern agriculture is characterised by extensive, large-scale monoculture, and depends on high chemical inputs and intensive mechanization. Although productive as defined by the one-dimensional measure of 'yield', its over-reliance on chemical pesticides, herbicides and synthetic fertilisers comes with a string of negative impacts on health and the environment: health risks to farm workers, harmful chemical residues on food, reduced biodiversity, deterioration of soil and water quality, and increased risks of crop disease. Modern monoculture also often marginalizes small farmers, particularly those in developing countries, the majority of farmers worldwide. GM crops, now thrown into the package, are threatening further health and environmental hazards (see Part 2).

In contrast, sustainable agricultural approaches place the emphasis on a diversity of local natural resources, and local autonomy of farmers to decide what they will grow and how they can improve their crops and livelihood. Agriculture is sustainable when it is ecologically sound, economically viable, socially just, culturally appropriate, humane and based on a holistic approach. A brief summary of key criteria, as elaborated by Pretty and Hine [89], follows (Box 4):

Box 4

Sustainable agriculture

- Makes best use of nature's goods and services by integrating natural, regenerative processes e.g. nutrient cycling, nitrogen fixation, soil regeneration and natural enemies of pests
- Minimises non-renewable inputs (pesticides and fertilisers) that damage the environment or harm human health
- Relies on the knowledge and skills of farmers, improving their self-reliance
- Promotes and protects social capital - people's capacities to work together to solve problems
- Depends on locally-adapted practices to innovate in the face of

uncertainty

- Is multifunctional and contributes to public goods, such as clean water, wildlife, carbon sequestration in soils, flood protection and landscape quality

Sustainable agricultural approaches may come under many names - agroecology, sustainable agriculture, organic agriculture, ecological agriculture, biological agriculture - but have the above criteria in common.

For example, organic farming largely excludes synthetic pesticides, herbicides and fertilisers. Instead, it is an ecosystem approach that manages ecological and biological processes, such as food web relations, nutrient cycling, maintaining soil fertility, natural pest control and diversifying crops and livestock. It relies on locally or farm-derived renewable resources, while remaining environmentally and ecologically viable.

While many in developed countries may be familiar with certified organic production, this is just the tip of the iceberg in terms of land managed organically but not certified as such. *De facto* or non-certified organic farming is usually prevalent in resource-poor and/or agriculturally marginal regions where local populations have limited engagement with the cash economy [90]. Farmers here rely on local natural resources to maintain soil fertility and to combat pests and diseases. They have sophisticated systems of crop rotation, soil management, and pest and disease control, based on traditional knowledge.

Likewise, agroecology relies on technologies that are cheap, accessible, risk averting and productive in marginal environments; that enhance ecological and human health; and that are culturally and socially acceptable [91]. Agroecological models emphasise biodiversity, nutrient recycling, synergy among crops, animals, soils and other biological components, as well as regeneration and conservation of resources. They rely on indigenous farming knowledge and incorporate low-input modern technologies to diversify production. The approach combines ecological principles and local resources in managing farming systems, providing an environmentally sound and affordable way for small farmers to intensify production in marginal areas. These agroecological alternatives can solve the agricultural problems that GM crops are supposed to solve, but do so in a much more socially equitable and environmentally harmonious manner [3].

There are countless studies as well as scientific research papers documenting the successes and benefits of sustainable agricultural approaches, which have been reviewed recently by the Food and Agriculture Organization of the United Nations [92] and ISIS [93].

We summarise the evidence on some of the benefits of agroecology, sustainable agriculture and organic farming for the environment and health, as well as for food security and the social well-being of farmers and local communities. It makes the case for a comprehensive shift to these sustainable agriculture approaches in place of GM crops.

Fifteen

Higher or Comparable Productivity & Yields

Organic agriculture is often criticised for having lower yields compared to conventional monoculture. While that may be the case in industrialised countries, such comparisons are misleading because they discount the costs of conventional monoculture in degraded land, water, biodiversity and other ecological services on which sustainable food production depends [92].

And merely looking at yields for single crops - as critics often do - misses other indicators of sustainability and higher actual productivity per unit area, particularly with agroecological systems that often have a diverse mixture of crops, trees and animals together on the land [94] (see "Efficient, Profitable Production"). It is often possible to obtain the highest yield of a single crop by planting it alone - in a monoculture. But while a monoculture may allow for a high yield of one crop, it produces nothing else of use to the farmer [95].

In any case, because of the damage done by conventional farming, a transition period is usually required to restore the land for the full benefits of sustainable farming. After the system is restored, comparable and often higher yields are obtained. With low-input, traditional agriculture, conversion to sustainable approaches is normally accompanied by immediately increased yields.

In fact, just reducing average farm size in most countries would stimulate increases in production far beyond the most optimistic biotech industry projections for GM crops. Small farms are more productive, more efficient, and contribute more to economic development than large farms, and small farmers are also better stewards of natural resources [95].

Research from around the world has revealed that smaller farms are from 2 to 10 times more productive per hectare than larger farms, which tend to be inefficient, extensive monocultures. Yield increases are achieved by using technological approaches based on agroecological principles that emphasize diversity, synergy, recycling and integration; and social processes that emphasize community participation and empowerment. As average farm sizes are usually in the larger, more inefficient range, genuine land reform offers an opportunity to boost production while lessening poverty.

The success of sustainable agriculture has been concretely demonstrated in a review of 208 projects and initiatives from 52 countries [89]. Some 8.98 million farmers have adopted sustainable agriculture practices on 28.92 million hectares in Africa, Asia and Latin America. Reliable data on yield changes in 89 projects show that farmers have achieved substantial increases in food production per hectare, about 50-100% for rainfed crops, though considerably greater in a few cases, and 5-10% for irrigated crops (though generally starting from a higher absolute yield base). These projects included both certified and non-certified organic systems, and integrated as well as near-organic systems. In all cases where reliable data were available, there were increases in per hectare productivity for food crops and maintenance of existing yields for fibre [92].

Some specific examples of increased yields are as follows:

- Soil and water conservation in the drylands of Burkina Faso has transformed formerly degraded lands. The average family has shifted from a cereal deficit of 644 kg per year (equivalent to 6.5 months of food shortage) to producing an annual surplus of 153 kg.
- Through the Cheha Integrated Rural Development Project in Ethiopia, some 12 500 households adopted sustainable agriculture, resulting in a 60% increase in crop yields.
- In Madagascar, a system of rice intensification improved rice yields from some 2 t/ha to 5,10 or 15 t/ha, without recourse to purchased inputs of pesticides or fertilisers.
- In Sri Lanka, some 55 000 households on about 33 000 ha have adopted sustainable agriculture, with substantial reductions in insecticide use. Yields have increased by 12-44% for rice and 7-44% for vegetables.
- 45 000 families in Honduras and Guatemala increased crop yields from 400-600 kg/ha to 2,000-2,500 kg/ha using green manures, cover crops, contour grass strips, in-row tillage, rock bunds and animal manures.
- The states of Santa Caterina, Paraná and Rio Grande do Sol

in southern Brazil have focused on soil and water conservation using contour grass barriers, contour ploughing and green manures. Maize yields have risen by 67% from 3 to 5 tonne/ha, and soybeans by 68% from 2.8 to 4.7 t/ha.

- The high mountain regions of Bolivia are some of the most difficult areas in the world for growing crops. Despite this, farmers have increased potato yields by three fold, particularly by using green manures to enrich the soil.

Other case studies of organic and agroecological practices show dramatic increases in yields as well as benefits to soil quality, reduction in pests and diseases and general improvement in taste and nutritional content [90]. For example:

- In Brazil, use of green manures and cover crops increased maize yields by 20-250%.
- In Tigray, Ethiopia, yields of crops from composted plots were 3-5 times higher than those treated only with chemicals.
- Yield increases of 175% are reported from farms in Nepal adopting agroecological practices.
- In Peru, restoration of traditional Incan terracing has led to increases of 150% for a range of upland crops. Farmers are able to produce bumper crops despite floods, droughts, and the lethal frosts common at altitudes of nearly 4,000 meters [94].
- Projects in Senegal involving 2 000 farmers promoted stall-fed livestock, composting systems, green manures, water harvesting systems and rock phosphate. Millet and peanut yields increased dramatically, by 75-195% and 75-165%, respectively. Because the soils have greater water retaining capacity, yield fluctuations are less pronounced between high and low rainfall years.
- In Santa Catarina, Brazil, focus has been on soil and water conservation, using contour grass barriers, contour ploughing and green manures. Some 60 different crop species, leguminous and non-leguminous, have been inter-cropped or planted during fallow periods. These have had major impacts on yields, soil quality, levels of biological activity and water-retaining capacity. Maize and soybean yields have increased by 66%.

- In Honduras, soil conservation practices and organic fertilisers have tripled or quadrupled yields.

A particular example is the *mucuna* bean improving crop yields on steep, easily eroded hillsides with depleted soils in Honduras [96]. Farmers first plant *mucuna*, which produces vigorous growth that suppresses weeds. When the beans are cut down, maize is planted in the resulting mulch. Subsequently, beans and maize are grown together. Very quickly, as the soil improves, yields are doubled, even tripled. The reason - *mucuna* produces lots of organic material, creating rich, friable soils. It also produces its own fertiliser, fixing atmospheric nitrogen (N) and storing it in the ground for other plants.

This simple technology has also been adopted in Nicaragua, where more than 1 000 peasants recovered degraded land in the San Juan watershed in just one year. These farmers have decreased the use of chemical fertilisers from 1 900 to 400 kilograms per hectare while increasing yields from 700 to 2 000 kilograms per hectare. Their production costs are about 22% lower than those for farmers using chemical fertilisers and monocultures [94].

Organic farming also compares favourably against conventional monoculture in industrialised countries. A review of scientifically replicated research results from seven different US universities and data from two research centres over 10 years show that yields from organic systems are comparable to those from conventional monoculture [97].

- Corn: With 69 total cropping seasons, organic yields were 94% of conventionally produced corn.
- Soybeans: Data from five states with 55 growing seasons showed organic yields were 94% of conventional yields.
- Wheat: Two institutions with 16 cropping years showed that organic wheat produced 97% of the conventional yields.
- Tomatoes: 14 years of comparative research on tomatoes showed no yield differences.

Results from the first 15 years of a long-term, large scale experiment carried out by the Rodale Institute show that after a transition period of 4 years, crops grown under organic systems (animal- and legume-based) yield as well as and sometimes better than crops grown under the conventional system [98]. Additionally, organic systems can outproduce the conventional system when conditions are less that optimal, for example during drought (see “Better Soils”). The initial lower yields were attributed partly to inadequate available N, the time taken for soil microbial activity to stabilise (soils generally contained enough total N but not yet in a usable form) and heavier weed growth. These could be addressed by appropriate management and given time for the system to adjust to the shift to organic farming.

A 4-year study, part of a larger, longer-term Sustainable Agriculture Farming Systems (SAFS) project at University of California, Davis, compared conventional and alternative farming systems for tomatoes [99]. Results indicate that organic and low-input production gave comparable yields to conventional systems. N availability was the most important yield-limiting factor in organic systems, but could be addressed by appropriate management. Additional N, when associated with high carbon inputs, built soil organic matter, providing long-term fertility benefits. Eventually, soil organic matter levels stabilised and N input requirements declined.

Results from the first 8 years of the SAFS project show that the organic and low-input systems had yields comparable to the conventional systems in all crops that were tested - tomato, safflower, corn and bean - and in some instances yielding higher than conventional systems [100]. Tomato yields in the organic system were lower in the first three years, but reached the levels of the conventional in subsequent years and had higher yields in the last year of the experiment (80 t/ha compared to 68 t/ha in 1996). Both organic and low-input systems resulted in increased soil organic carbon content and larger pools of stored nutrients, each critical for long-term fertility maintenance. As soil organic matter levels stabilised during the last two years of the experiment, resulting in more N availability, higher yields of organic crops were observed then. The organic systems were found to be more profitable in both corn and tomato, mainly due to higher price premiums.

Phosphorus (P) is the most important nutrient (after N) most frequently deficient in soils of tropical Africa. Unlike N, P cannot be added to the soil by biological fixation. Therefore, application of P from organic and inorganic sources is essential to maximise and sustain high crop yield potential. Field studies compared the impact of organic and inorganic fertilisers on extractable P availability and maize yields in western Kenya [101]. P input was thought to be a major factor affecting yields. The scientists concluded that reasonable maize yields could be achieved in smallholder systems if adequate amounts of high quality organic materials were used as P sources.

Another experiment examined yield, vitamin and mineral content of organic and conventional potatoes and sweet corn over 3 years [102]. Results showed that yield and vitamin C content of potatoes were not affected by the two different regimes. While one variety of conventional corn out-produced the organic, there was no difference between conventional and organic in the yield of another variety, or in vitamin C or E contents of corn kernels. Results show that long-term application of composts produces higher soil fertility and comparable plant growth.

Sixteen

Better Soils

Most sustainable agricultural practices reduce soil erosion and improve soil physical structure, organic matter content, water-holding capacity and nutrient balances. Soil fertility is maintained on existing lands and restored on degraded lands.

A powerful example is that of farmers along the Sahara's edge, in Nigeria, Niger, Senegal, Burkina Faso and Kenya, farming productively without destroying soils, even in dryland areas. Integrated farming, mixed cropping and traditional soil and water conservation methods are increasing per capita food production several fold [103, 104].

Indeed, sustainable agricultural approaches are helping to conserve and improve the farmers' most precious resource - the topsoil. To counter the problems of hardening, nutrient loss and erosion, organic farmers in the South are using trees, shrubs and legumes to stabilise and feed soil, dung and compost to provide nutrients, and terracing or check dams to prevent erosion and conserve groundwater [90].

Planting *mucuna* beans in Latin America, for example, has restored soil fertility on depleted soils [96]. *Mucuna* produces 100 tonnes of organic material per hectare, creating rich, friable soils in just 2-3 years. It also produces its own fertiliser, fixing atmospheric N and storing it in the ground for use by other plants. As the soil improves, yields are doubled, even tripled.

One of the longest running agricultural trials on record (more than 150 years) is the Broadbalk experiment at Rothamsted Experimental Station. The trials compare a manure-based fertiliser farming system to a synthetic chemical fertiliser system. Wheat yields are on average slightly higher in organically fertilised plots than in plots receiving chemical fertilisers. More importantly, soil fertility, measured as soil organic matter and nitrogen levels, increased by 120% over 150 years in the organic plots, compared with only a 20% increase in chemically fertilised plots [105].

The world's longest running experiment comparing organic and conventional farming pronounced chemical-free farming a success [106, 107]. The 21-year Swiss study found that soils nourished with manure were more fertile and produced more crops for a given input of nitrogen or other fertiliser. The biggest bonus was improved soil quality under organic cultivation. Organic soils had up to 3.2 times as much biomass and abundance of earthworms, twice as many arthropods (important predators and indicators of soil fertility) and 40% more mycorrhizal fungi colonising plant roots. Mycorrhizal fungi are important in helping roots obtain more nutrients and water from the soil [108]. The increased diversity of microbial communities in organic soils transformed carbon from organic debris into biomass at lower energy costs, building up a higher microbial biomass; hence a more diverse microbial community is more efficient in resource utilisation. The enhanced soil fertility and higher biodiversity in organic soils is thought to reduce dependency on external inputs and provide long-term environmental benefits.

Field experiments conducted at three organic and three conventional vegetable farms in 1996-1997 examined the effects of synthetic fertilisers and alternative soil amendments, including compost [109]. Propagule densities of *Trichoderma* species (beneficial soil fungi that are biological control agents of plant-pathogenic fungi) and thermophilic micro-organisms (a major constituent of which was Actinomycetes, which suppresses *Phytophthora*) were greater in organic soils. In contrast, densities of *Phytophthora* and *Pythium* (both plant pathogens) were lower in organic soils. While the study recorded increased enteric bacteria in organic soils, the scientists stressed that this wasn't a problem, as survival rates in soil are minimal. (Critics of organic farming disingenuously point to the possible health effects of using manure. But untreated manure is *not* allowed in certified organic culture, and treated manure (known widely as compost) is safe - this is what is used in organic farming. Unlike conventional regimes (where untreated manure might be used), organic certification bodies inspect farms to ensure standards are met [110].)

Few significant differences in yields were observed between soils with alternative amendments and those with synthetic fertilisers, regardless of production system. In 1997, when all growers planted tomatoes, the yields were higher on farms with a history of organic production, regardless of soil amendment type, due to the benefits of long-term organic amendments. Mineral concentrations were higher in organic soils, and soil quality in conventional farms was significantly improved by organic fertiliser. The researchers concluded, “the argument [of critics] that organic farming is equivalent to low yield farming is not supported by our data" (p.158).

Another study compared ecological characteristics and productivity of 20 commercial farms in the Central Valley of California [111]. Tomato yields were shown to be quite similar in organic and conventional farms. Insect pest damage was also comparable. However, significant differences were found in soil health indicators such as N mineralisation potential and microbial abundance and diversity, which were higher in the organic farms. N mineralisation potential was three times greater in organic compared to conventional fields. The organic fields also had 28% more organic carbon. The increased soil health in the organic farms resulted in considerably lower disease incidence. Severity of the most prevalent disease in the study, tomato corky root disease, was significantly lower in the organic farms

The 15-year study carried out by the Rodale Institute compared three maize/soybean agroecosystems [98, 112, 113]. One was a conventional system using mineral N fertiliser and pesticides. The other two systems were managed organically. One was manure-based, where grasses and legumes, grown as part of a crop rotation, were fed to cattle. The manure provided N for maize production. The other system did not have livestock but leguminous cover crops were incorporated into soil as a source of N.

Organic techniques were found to significantly improve soil quality, as measured by structure, total soil organic matter (a measure of soil fertility) and biological activity [98]. The improved soil structure created a better root-zone environment for growing plants and allowed the soil to better absorb and retain moisture. Apart from the benefit during low-rainfall periods, it reduced the potential for erosion in severe storms. Organic soils showed a higher level of microbial activity and a greater diversity of micro-organisms. Such long-term changes in the character of the soil community can promote plant health and may positively affect the way nutrients such as carbon and nitrogen are made available to plants and cycled in the soil. Amazingly, 10-year-average maize yields differed by less than 1% among the three systems, which were nearly equally profitable [112,113]. N content increased markedly in the manure system (and, to a lesser degree, in the legume system), but was unchanged or declined in the conventional system. The two organic systems show increasing levels of available N, while N levels are declining in the conventional system. This indicates that the organic systems are more sustainable, in terms of productivity, over the long term [98].

The soybean production systems were also highly productive, achieving 40 bushels/acre. In 1999, during one of the worst droughts on record, yields of organic soybeans were 30 bushels/acre, compared to only 16 bushels/acre from conventionally grown soybeans. Not only do organic practices encourage the soil to hold moisture more efficiently than conventionally managed soil, the higher organic matter content also makes organic soil less compact so that roots can penetrate more deeply to find moisture. The results highlight the benefits to soil quality organic farming brings, and its potential to avert crop failures. “Our trials show that improving the quality of the soil through organic practices can mean the difference between a harvest or hardship in times of drought”, said Jeff Moyer, Farm Manager at Rodale Institute [114].

Seventeen

Cleaner Environment

Sustainable agriculture systems that use no, or little, chemical pesticides or herbicides are obviously a benefit to the environment (see next section). Conventional farming systems are moreover often associated with problems such as nitrate leaching and groundwater pollution. Application of phosphorus (P) fertilisers in excess of plant needs results in accumulation of available P in topsoils, and increased losses to surface water.

Water eutrophication is one of the starkest results of N and P pollution. The high nutrient concentrations stimulate algal blooms, which block sunlight, causing aquatic vegetation to die and in the process destroying valuable habitat, food and shelter for aquatic life. When the algae die and decompose, oxygen is used up, to the detriment of aquatic life.

Four farming systems: organic, low-input, conventional 4-year rotation and conventional 2-year rotation were evaluated for soil mineral N, potentially mineralisable N (PMN), crop yields and weed biomass in irrigated processing tomatoes and corn from 1994 to 1998 in California's Sacramento Valley [115]. The organic and low-input systems showed 112% and 36% greater PMN pools than the conventional systems, respectively, but as they used cover-crops, there was a slower, more continuous release of mineral N throughout the growing season. In contrast, conventional systems supplied mineral N in intervals from synthetic fertilisers, and N mineralisation rates were 100% greater than in the organic and 28% greater than in the low-input system, thus implying a greater likelihood of N leaching and associated pollution problems in conventional systems. Average tomato and corn yields for the 5-year period were not significantly different among the farming systems. The researchers concluded that the lower potential risk of N leaching from lower N mineralisation rates in the organic and low-input farming systems appear to improve agricultural sustainability and environmental quality while maintaining similar crop yields to conventional systems.

The 21-year Swiss study [106, 107] also assessed the extent to which organic farming practices would affect the accumulation of total and available phosphorus (P) in soil, compared to conventional practices [116]. Soil samples were taken from a non-fertilised control, two conventionally cultivated treatments and two organically cultivated treatments. Average annual P budgets of both organic farming systems were negative for each single rotation period and for the 21 years of field experimentation. This indicates that P removal by harvested products exceeded the P input by fertilisers. The conventionally cultivated soil, receiving mineral fertilisers and farmyard manure, showed a positive budget over all three rotations. Furthermore, the inorganic P availability in the topsoil decreased markedly in all treatments during the field trial except in the conventional treatment. Thus the potential for P pollution from organic systems is reduced.

The 15-yr trials carried out by the Rodale Institute showed that the conventional system had greater environmental impacts - 60% more nitrate leached into groundwater over a 5-year period than in the organic systems [112, 113]. Soils in the conventional system were also relatively high in water-soluble carbon, hence vulnerable to leaching out. The better water infiltration rates of the organic systems made them less prone to erosion and less likely to contribute to water pollution from surface runoff.

Eighteen

Reduced Pesticides & No Increase in Pests

Many sustainable agriculture projects report large reductions in pesticide use following the adoption of integrated pest management.

In Vietnam, farmers have cut the number of sprays from 3.4 to 1.0 per season, in Sri Lanka from 2.9 to 0.5 per season, and in Indonesia from 2.9 to 1.1 per season. Overall, in South-east Asia, 100,000 small rice farmers involved in integrated pest management substantially increased yields while eliminating pesticides [89].

Because organic procedures exclude synthetic pesticides, critics claim that losses due to pests would rise. However, research on Californian tomato production contradicted this claim [117]. There was no significant difference in levels of pest damage in 18 commercial farms, half of which were certified organic systems and half, conventional operations. Arthropod biodiversity was on average one-third greater in organic farms than in conventional farms. There was no significant difference between the two in herbivore (pests) abundance. However, densities of natural enemies of pests were more abundant in organic farms, with greater species richness of all functional groups (herbivores, predators, parasitoids). Thus, any particular pest species in organic farms would be associated with a greater variety of herbivores (i.e. would be diluted) and subject to a wider variety and greater abundance of potential parasitoids and predators.

At the same time, research shows that pest control is achievable without pesticides, actually reversing crop losses. In East Africa, maize and sorghum face two major pests - stem borer and Striga, a parasitic plant. Field margins are planted with 'trap crops' that attract stem borer, such as Napier grass and Sudan grass. Napier grass is a local weed whose odour attracts stem borer. Pests are lured away from the crop into a trap - the grass produces a sticky substance that kills stem borer larvae [118]. The crops are inter-planted with molasses grass (*Desmodium uncinatum*) and two legumes: silverleaf and greenleaf. The legumes bind N, enriching the soil. *Desmodium* also repels stem borers *and* Striga.

In Bangladesh, a project since 1995 has promoted non-chemical means of pest control in rice, relying solely on natural enemies and the ability of the rice plant to compensate for insect damage, with no negative effects on yields [119]. The yields of farmers using no insecticide are consistently higher than those of insecticide users. Since project participants also modify other practices besides foregoing insecticides, it cannot be said that the yield increase is due entirely to the absence of insecticides. It does show, however, that insecticides are not needed to obtain yield increases. Project participants have higher net returns than insecticide users. In 1998, the average net return from the rice crop of participants, if they sold the entire crop, was Tk5,373 (US$107) per farmer per season, as opposed to Tk3,443 (US$69) per farmer per season for insecticide users.

Besides the obvious benefit of not using harmful pesticides, Korean researchers have reported that avoiding pesticides in paddy fields encourages the muddy loach fish, which effectively control the mosquitoes that spread malaria and Japanese encephalitis [120]. Fields in which no insecticides were used had a richer variety of insect life. However, the fish are voracious predators of the mosquito larvae, and as such larvae numbers were significantly lower in these organic sites.

Similarly, in Japan, an innovative organic farmer has pioneered a rice growing system that turns weeds and pests into resources for raising ducks [121]. The ducks eat insect pests and the golden snail that attack rice plants, and also eat the seeds and seedlings of weeds. By using their feet to dig up the weed seedlings, the ducks aerate the water and provide mechanical stimulation to make the rice stalks strong and fertile. This practice has been adopted by about 10,000 farmers in Japan, and by farmers in South Korea, Vietnam, the Philippines, Laos, Cambodia, Thailand and Malaysia. Many farmers increased their yield 20 to 50% or more in the first year. One farmer in Laos increased his income three-fold. Systems such as these, which are characteristic of sustainable agricultural approaches, make use of the complex interactions of different species, and show how important the relationship between biodiversity and agriculture is (see next section).

Nineteen

Supporting Biodiversity & Using Diversity

Maintaining agricultural biodiversity is vital to ensuring long-term food security. Pimbert has reviewed the multiple functions of agricultural biodiversity, and its links with rural livelihoods [122]. Agricultural biodiversity contributes to food and livelihood security, efficient production, environmental sustainability and rural development; it regenerates local food systems and rural economies. Rural people have dynamic and complex livelihoods, which usually rely on diversity of plant and animal species, both wild and under different stages of domestication. Diversity *within* species (i.e. farmers' varieties or landraces) is also remarkable among the species domesticated for crop and livestock production, resulting from rural people's innovation. Such agricultural genetic diversity is a vital insurance against crop and livestock disease outbreaks, and improves the long-term resilience of rural livelihoods in the face of adverse trends or shocks. Agricultural biodiversity is, however, increasingly threatened by the adoption of high-yielding, uniform cultivars and varieties in modern monoculture.

The proceedings of a FAO meeting held in October 2002 on 'Biodiversity and the Ecosystem Approach in Agriculture, Forestry and Fisheries' highlighted the inter-connectedness of biodiversity and agriculture, with specific examples of how farmer innovations contribute to enhancing biodiversity, as well as the importance of biodiversity for agriculture [123]. One paper reviewed 16 case studies from 10 countries in Asia, Latin America, Europe and Africa, showing how organic agriculture contributes to agricultural biodiversity, including genetic resources for food and agriculture [124]. In all cases, there is a close relationship between organic systems and the maintenance of biodiversity, and a resulting improvement in farmers' socio-economic situations.

Case studies from a community-based system of organic farming in Bangladesh, *ladang* cultivation of organic spices in Indonesia, and organic coffee production in Mexico, show how traditional and community-based management can rehabilitate abandoned and degraded agroecosystems. These polyculture systems are characterised by highly diversified ecosystems and improved agricultural biodiversity, which provide not only food, but also generate further community services. Case studies of organic cocoa farming in Mexico and organic, naturally pigmented cotton in Peru are examples of successful organic agriculture that have contributed to *in situ* conservation and sustainable use in centres of diversity, while providing economic benefits for the communities concerned. Traditional and under-utilised species and varieties in Peru (gluten-free quinoa), Italy (Saraceno grain, Zolfino bean, spelt wheat) and Indonesia (local varieties of rice) have been rescued from extinction, facilitated by organic agriculture. Four further case studies, from Germany, Italy, South Africa and Brazil, illustrate how organic farming has restored many traditional varieties and breeds that are better adapted to local ecological conditions and that are resistant to disease. The authors conclude that organic agriculture contributes to the *in situ* conservation, restoration and maintenance of agricultural biodiversity.

Furthermore, sustainable agriculture plays an important role in conserving natural biodiversity. Organic farms often exhibit greater biodiversity than conventional farms, with more trees, a wider diversity of crops and many different natural predators, which control pests and help prevent disease [90].

Research carried out in Colombia and Mexico showed 90% fewer bird species in sun-grown coffee plantations as opposed to shade-grown organic coffee, which mimics the forests' natural structure [125]. Shade cultivation is recommended by organic standards as it fulfils requirements to enhance soil fertility, pest and disease control and expands crop production options. Another study by the British Trust for Ornithology found significantly higher breeding densities of skylark (an endangered species) on organic farms, compared to conventional farms.

A report from the Soil Association [126] comprehensively reviews the findings of nine studies (seven from the UK, two from Denmark), and summarizes the key findings of fourteen additional studies, on the biodiversity supported by organic farming. The report concludes that organic farming in the lowlands supports a much higher level of biodiversity (both abundance and diversity of species) than conventional farming systems, including species that have significantly declined.

This was particularly true for wild plants in arable fields; birds and breeding skylarks; invertebrates including arthropods that comprise bird food; non-pest butterflies; and spiders. Conversely, organic farms showed significant decrease in pest aphid numbers and no change in the numbers of pest butterflies. Habitat quality was more favourable on organic farms, both in terms of field boundaries and crop habitats. Many beneficial practices are identified with organic agriculture, such as crop rotations with grass leys, mixed spring and autumn sowing, more permanent pasture, no application of herbicides or synthetic pesticides, and use of green manure. These practices can reverse the trends in decline of biodiversity associated with conventional farming. Generally, the improvements in biodiversity were found across the cropped areas as well as at the field margins. The report also suggests that major benefits are likely in the uplands.

The reduced or non-use of agrochemicals in organic and sustainable farming will also allow wild plant species to flourish, among which are an increasing number of herbs used in traditional medicines. The World Health Organisation estimates that 75-80% of the world’s population use plant medicines either in part or entirely for health care. Some of these wild plant species are facing extinction, and concerted effort is needed for their local conservation, while ensuring that harvesting from the wild is sustainable and continues to contribute to local people's livelihood [127]. Wild plants and animals are also part of an important repertoire of food and medicines for many farming communities [122].

Biodiversity is an important and integral part of sustainable agricultural approaches. Each species in an agroecosystem is part of a web of ecological relationships connected by flows of energy and materials. In this sense, the different components of agrobiodiversity are multifunctional, and contribute to the resilience of production systems while providing environmental services, although some species may play key driving roles [122]. The environmental services provided by agricultural biodiversity include soil organic matter decomposition, nutrient cycling, biomass production and yield efficiency, soil and water conservation, pest control, pollination and dispersal, biodiversity conservation, climate functions, water cycling, and influence on landscape structure.

Empirical evidence from a study conducted since 1994 shows that biodiverse ecosystems are 2-3 times more productive than monocultures [128, 129]. In experimental plots, both aboveground and total biomass increased significantly with species number. The high diversity plots were fairly immune to the invasion and growth of weeds, but this was not so for monocultures and low diversity plots. Thus, biodiverse systems are more productive, and less prone to weeds as well!

Proving with stunning results that planting a diversity of crops is beneficial (compared with monocultures), thousands of Chinese rice farmers have doubled yields and nearly eliminated its most devastating disease without using chemicals or spending more [130, 131]. Scientists worked together with farmers in Yunnan, who implemented a simple practice that radically restricted the rice blast fungus that destroys millions of tons of rice and costs farmers several billion dollars in losses each year. Instead of planting large stands of a single type of rice, as they typically do, farmers planted a mixture of two different kinds: a standard hybrid rice that doesn’t usually succumb to rice blast and a much more valuable glutinous or ‘sticky’ rice known to be very susceptible. The genetically diverse rice crops were planted in all the rice fields in five townships in 1998 (812 hectares), and ten townships in 1999 (3 342 hectares).

Disease-susceptible varieties planted with resistant varieties had 89% greater yield, and blast was 94% less severe than when grown in monoculture. Both glutinous and hybrid rice showed decreased infection. The hypothesis is fairly clear for glutinous rice. If a variety is susceptible to a disease, the more concentrated those susceptible types are, the more easily disease spreads. It is less likely to spread when susceptible plants are grown among plants resistant to the disease (i.e. a dilution effect occurs). The glutinous rice plants, which rise above the shorter hybrid rice, also enjoyed sunnier, warmer and drier conditions that discouraged fungal growth. Disease reduction in the hybrid variety is likely explained by the taller glutinous rice blocking the airborne spores of rice blast, and by greater induced resistance (due to diverse fields supporting diverse pathogens with no single dominant strain). The gross value per hectare of the mixtures was 14% greater than hybrid monocultures and 40% greater than glutinous monocultures.

In Cuba, integrated farming systems or polycultures, such as cassava-beans-maize, cassava-tomato-maize, and sweet potato-maize have productivity 1.45 to 2.82 times greater than that of monocultures [94]. In addition, legumes improve the physical and chemical characteristics of soil and effectively break the cycle of insect-pest infestations.

Integrating vegetables into rice farming systems in Bangladesh by planting them on dikes doesn't affect rice yields, despite the area lost to dike crops [119]. Instead, the vegetables provide families with more nutrients. The surplus is shared with neighbours, friends and relatives or sold, providing an added value of 14%. Integrating fish into flooded rice systems also caused no significant decline in rice yields, and in some cases increased yields. Net returns from selling the fish average Tk7,354 (US$147) per farmer per season, more than the returns from rice. As with vegetables, rice-fish farmers eat fish more frequently and donate much of it to their social networks.

Soil biodiversity also plays a crucial role in promoting sustainable and productive agriculture, and organic practices help enhance this [132]. Organic mulch, applied judiciously to degraded and crusted soil surfaces in the Sahelian region of Burkina Faso, triggered termite activity, promoting the recovery and rehabilitation of degraded soils. Termites feeding on or transporting surface-applied mulch improved soil structure and water infiltration, enhancing nutrient release into the soil. The growth and yield of cowpeas were far better on plots with termites than on plots without. In India, organic fertilisers and vermicultured earthworms applied in trenches between tea rows increased tea yields by 76-239%, compared to conventional inorganic fertilisation. Profits increased accordingly.

Twenty

Environmental & Economic Sustainability

Research published in *Nature* investigated the sustainability of organic, conventional and integrated (combining both methods) apple production systems in Washington from 1994-1999 [133, 134]. The organic system ranked first in terms of environmental and economic sustainability, the integrated system second and the conventional system last. The indicators used were soil quality, horticultural performance, orchard profitability, environmental quality and energy efficiency.

Soil quality ratings in 1998 and 1999 for the organic and integrated systems were significantly higher than for the conventional system, due to the addition of compost and mulch. All three systems gave comparable yields, with no observable differences in physiological disorders or pest and disease damage. There were satisfactory levels of nutrients for all. A consumer taste test found organic apples less tart at harvest and sweeter than conventional apples after six months of storage.

Organic apples were the most profitable due to price premiums and quicker investment return. Despite initial lower receipts in the first three years, due to the time taken to convert to certified organic farming, the price premium in the next three years averaged 50% above conventional prices. In the long term, the organic system recovered costs faster. The study projected that the organic system would break even after 9 years, but that the conventional system would do so only after 15 years, and the integrated system, after 17 years.

Environmental impact was assessed by a rating index to determine potential adverse impacts of pesticides and fruit thinners: the higher the rating, the greater the negative impact. The rating of the conventional system was 6.2 times that of the organic system. Despite higher labour needs, the organic system expended less energy on fertiliser, weed control and biological control of pests, making it the most energy efficient.

Another study evaluated the financial and environmental aspects of sustainability of organic, integrated and conventional farming systems by applying an integrated economic-environmental accounting framework to three case study farms in Tuscany, Italy [135]. In terms of financial performance, the gross margins of steady-state organic farming systems were higher than the corresponding conventional farming systems' gross margins. The organic systems performed better than the integrated and conventional systems with respect to nitrogen losses, pesticide risk, herbaceous plant biodiversity and most other environmental indicators. The results provided evidence that organic farming potentially improves the efficiency of many environmental indicators as well as is remunerative. While not fully conclusive that organic farming is more sustainable, nonetheless, the performance of organic farming systems was better than conventional farming systems.

A European-wide study assessed environmental and resource use impacts of organic farming, relative to conventional farming [136]. The study showed that organic farming performs better than conventional farming in relation to the majority of environmental indicators reviewed. In no category did organic farming show a worse performance when compared with conventional farming. For example, organic farming performed better than conventional farming in terms of floral and faunal diversity, wildlife conservation and habitat diversity. Organic farming also conserved soil fertility and system stability better than conventional systems. Furthermore, the study showed that organic farming results in lower or similar nitrate leaching rates than integrated or conventional agriculture, and that it doesn’t pose any risk of ground and surface water pollution from synthetic pesticides.

The FAO review [92] concludes, “As a final assessment, it can be stated that well-managed organic agriculture leads to more favourable conditions at *all* environmental levels” (italics added, p.62). Its assessment shows that organic matter content is usually higher in organic soils, indicating higher fertility, stability and moisture retention capacity, which reduce the risk of erosion and desertification. Organic soils have significantly higher biological activity and higher mass of micro-organisms, making for more rapid nutrient recycling and improved soil structure. The review found that organic agriculture poses no risk of water pollution through synthetic pesticides and that nitrate-leaching rates per hectare are significantly lower compared to conventional systems. In terms of energy use, organic agriculture performs better than conventional (see next section). The review established that agriculture genetic resources, including insects and micro-organisms, all increase when land is farmed organically, whilst wild flora and fauna within and around organic farms are more diverse and abundant. By offering food resources and shelter for beneficial arthropods and birds, organic agriculture contributes to natural pest control. It also contributes to the conservation and survival of pollinators.

Twenty-One

Ameliorating Climate Change

Modern agriculture has a lot to answer for in terms of contributing to climate change, which is by far and away the most daunting problem that humankind has ever encountered. It has increased emissions of nitrous oxide and methane, potent greenhouse gasses; it is fossil fuel energy intensive and contributes to the loss of soil carbon to the atmosphere [137].

Sustainable agricultural practices can provide synergistic benefit to ameliorating climate change. The FAO believes that organic agriculture enables ecosystems to better adjust to the effects of climate change and has major potential for reducing agricultural greenhouse gas emissions [92].

Organic agriculture is more energy efficient than conventional agriculture in apple production systems [133, 134]. While, on a per output unit scale, CO2 emissions are similar or tend to be higher in organic farming systems in Europe, on a per hectare scale, CO2 emissions for organic farming were found to be 48-66% lower than for conventional farming [136]. This was attributed to the characteristics of organic agriculture, i.e., no input of mineral N fertilisers with high energy consumption, lower use of high energy consuming feedstuffs, lower input of mineral fertilisers (P, K) and elimination of pesticides.

Research in Finland showed that while organic farming uses more machine hours than conventional farming, total energy consumption is still lowest in organic systems [138]. In conventional systems, more than half of total energy consumed in rye production is spent on the manufacture of pesticides. Studies in Denmark compared organic and conventional farming for milk and barley grain production. The total energy used per kilogram of milk produced was lower in the organic than in the conventional dairy farm, while the total energy used to grow a hectare of organic spring barley was 35% *lower* than used to produce conventional spring barley on the same area [139]. However, organic yield was lower, thus energy used to produce one kg of barley was marginally lower for the organic than for the conventional. The Rodale Institute's trials found that energy use in the conventional system was

200% higher than in either of the organic systems [98].

The FAO review [92] concluded that, “Organic agriculture performs better than conventional agriculture on a per hectare scale, both with respect to direct energy consumption (fuel and oil) and indirect consumption (synthetic fertilizers and pesticides)”, with high efficiency of energy use (p.61).

Furthermore, because of sustainable agriculture’s focus on local production, consumption and distribution, less energy is wasted on transportation of products, particularly by air. According to a study carried out in 2001, greenhouse gas emissions associated with the transport of food from the local farm to a farmer’s market are 650 times lower than the average sold in supermarkets [cited in 137].

Soils are an important sink for atmospheric CO2, but this sink has been increasingly depleted by conventional agricultural land use. Sustainable agriculture approaches are however helping to counteract climate change by restoring soil organic matter content (see “Better Soils”), as these increase carbon fixation below ground. Organic matter is restored by the addition of manures, compost, mulches and cover crops.

Pretty and Hine suggest that the 208 projects they assessed accumulated some 55.1 million tonnes of carbon [89]. The SAFS Project found that organic carbon content of the soil increased in both organic and low-input systems [100], while the study of 20 commercial farms in California found that organic fields had 28% more organic carbon [111]. This was also true in the 15-year study by the Rodale Institute, where soil carbon levels increased in the two organic systems, but not in the conventional system [98]. The researchers concluded that organic systems showed significant ability to absorb and retain carbon, raising the possibility that sustainable agriculture practices can help reduce the impact of global warming.

The FAO also estimated that organic agriculture is likely to emit less nitrous dioxide (N2O) [92], another important greenhouse gas and also a cause of stratospheric ozone depletion. This is due to lower N inputs; less N from organic manure due to lower livestock densities; higher C/N ratios of applied organic manure and less available mineral N in the soil as a source of denitrification; and efficient uptake of mobile N in soils due to cover crops.

Twenty-Two

Efficient, Profitable Production

Any yield decrease in organic agriculture is more than made up for by its ecological and efficiency gains, and lower costs, making it a profitable venture. This was true of the Swiss study, which found that input of fertiliser and energy was reduced by 34-53% and pesticide input by 97%, whereas mean crop yield was only 20% lower over the 21 years, indicating efficient production and resource use [106, 107]. The organic approach was commercially viable in the long-term, producing more food per unit of energy or resources.

Data show that that smaller farms produce far more per unit area than larger farms (which tend to be monocultures characteristic of conventional farming) [95]. Though the yield per unit area of one crop may be lower on a small farm than on a large monoculture, the total output per unit area, often composed of more than a dozen crops and various animal products, can be far, far higher. Small farms are also more efficient than large ones in terms of land use and ‘total factor productivity’, an averaging of the efficiency of use of all the different factors that go into production, including land, labour, inputs, capital, etc.

Studies in Bolivia show that though yields are greater in chemically fertilised and machinery-prepared potato fields, energy costs are higher and net economic benefits lower, than where native legumes have been used as rotational crops [94]. Surveys indicate that farmers prefer this alternative system because it optimises the use of scarce resources, labour and available capital, and is accessible to even poor producers.

Two trials in Minnesota, initiated in 1989, each evaluated a 2-yr corn-soybean rotation and a 4-yr corn-soybean-oat/alfalfa-alfalfa crop rotation under four management strategies: zero, low, high and organic inputs [140]. Averaged across a 7-yr time frame from 1993-1999, corn and soybean yields in the 4-yr organic strategy were 91 and 93%, and 81 and 84%, respectively, of the 2-yr high input strategy. However, oat yields were similar with either the 4-yr organic or high input strategies, and alfalfa yield in the 4-yr organic strategy was 92% that of the 4-yr high input strategy in one trial, and in the second trial, yields were the same. Despite the slight reduction in corn and soybean yields, the organic strategy had lower production costs than the high input strategy. Consequently, net returns, without considering organic price premiums, for the two strategies were equivalent. The scientists suggested that organic production systems can be competitive with conventional ones.

A comprehensive review of the many comparison studies of grain and soybean production conducted by six Midwestern universities since 1978 found that in all these studies organic production was equivalent to, and in many cases better than, conventional [141]. Organic systems had higher yields than conventional systems that featured continuous crop production (i.e. no crop rotations), and equal or lower yields in conventional systems that included crop rotations. In drier climates, organic systems had higher yields, as they were more drought-hardy than conventional systems. The organic cropping systems were always more profitable than the most common conventional systems if organic price premiums were factored in. When the higher premiums were not factored in, the organic systems were still more productive and profitable in half the studies. This was attributed to lower production costs and the ability of organic systems to out-perform the conventional in drier areas, or during drier periods. The author concluded, “organic production systems are competitive with the most common conventional production systems”, and suggested that, “if farmers obtain current market premiums for organic grains and soybeans, their organic production generally delivers higher profits than non-organic grain and soybean production” (p.2).

The 15-year results from the Rodale Institute showed that after a transition period with lower yields, the organic systems were competitive financially with the conventional system [98]. While the costs of the transition are likely to affect a farm's overall financial picture for some years, projected profits ranged from slightly below to substantially above those in the conventional system, even though economic analyses did not assume any organic price premium. The higher profits for the organic farms came largely from higher corn yields, which nearly doubled after the transition. When prices or yields were low, organic farms suffered less than the conventional and had fewer income fluctuations, as they had a diversity of crops other than corn to sell. Expenses on the organic farms were significantly lower than on the conventional - the latter spent 95% more on fertilisers and pesticides. Overall production costs on the organic farms were 26% lower.

Twenty-Three

Improved Food Security & Benefits to Local Communities

Despite adequate global food production, many still go hungry because increased food supply does not automatically mean increased food security. What's important is who produces the food, who has access to the technology and knowledge to produce it, and who has the purchasing power to acquire it [89]. Poor farmers cannot afford expensive 'modern' technologies that theoretically raise yields.

Many farmers show 'lagging productivity', not because they lack 'miracle'seeds that contain their own insecticide or tolerate massive doses of herbicide, but because they have been displaced onto marginal, rain-fed lands, and face structures and macroeconomic policies that have built on historical inequalities and that are increasingly inimical to food production by small farmers [142]. As such, their agriculture is best characterised as 'complex, diverse and risk prone' [143], and they have tailored agricultural technologies to their variable but unique circumstances, in terms of local climate, topography, soils, biodiversity, cropping systems, resources, etc. It is these farmers, already risk-prone, who stand to be harmed most by the risks of GM crops [142].

Sustainable agricultural approaches must thus allow farmers to improve local food production with low-cost, readily available technologies and inputs, without causing environmental damage. This was indeed the case, as reviewed by Pretty and Hine [89]. Most sustainable agriculture projects and initiatives reported significant increases in household food production - some as yield improvements, some as increases in cropping intensity or diversity of produce.

The evidence showed:

- Average food production per household increased by 1.71 tonnes per year (up 73%) for 4.42 million farmers on 3.58 million hectares.
- Increase in food production was 17 tonnes per year (an

increase of 150%) for 146,000 farmers on 542,000 hectares cultivating roots (potato, sweet potato and cassava).

· Total production increased by 150 tonnes per household (an increase of 46%) for the larger farms in Latin America (average size 90 hectares).

They found that as food supply increased, domestic consumption also increased, with direct health benefits, particularly for women and children. Furthermore, 88% of the 208 projects made better use of locally-available natural resources, and 92% improved human capital through learning programmes. In more than half the projects, people worked together.

Evidence from hundreds of grassroots development projects show that increasing agricultural productivity with agroecological techniques not only increases food supplies, but also increases incomes, thus reducing poverty, increasing food access, reducing malnutrition and improving the livelihoods of the poor [144]. Data from thousands of successful experiences of sustainable agriculture implemented at the local level document numerous benefits. Agroecological systems lead to more stable levels of total production per unit area than high-input systems; they give economically favorable rates of return, provide a return to labour and other inputs for a livelihood acceptable to small farmers and their families, and ensure soil protection, conservation, and enhance agrobiodiversity [145].

Sustainable agricultural approaches recognise the value of traditional and indigenous knowledge, and of farmers' experience and innovation. The importance and value of learning from farmers, and of farmer-led participatory agricultural research, are well established in concepts such as 'farmer first' [143, 146].

The FAO review highlights the important contributions of resource poor farmers worldwide [92]. Non-certified organic agriculture, practiced by millions of indigenous people, peasants and small family farms make a significant contribution to regional food security: in Latin America they account for more than 50% of the maize, beans, manioc and potatoes produced; in Africa, most of the cereals, roots and tubers; in Asia, most of the rice. Case studies from India, Brazil, Iran, Thailand and Uganda show how traditional knowledge, innovation and agroecological approaches have brought benefits: increased productivity, better environmental health and soil fertility, improved biodiversity, economic benefits, food security, enhanced social relations within communities, and revival of traditional, sustainable agricultural practices.

Farmers in Ethiopia are taking steps to ensure their food security by relying on their knowledge [147]. In Ejere, farmers have reclaimed their own varieties of local wheat, teff (an Ethiopian staple cereal) and barley, after so-called modern high-yielding varieties actually resulted in lower yields and other problems. In the Butajira area, farmers are demonstrating that it is possible to farm intensively and sustainably to provide enough food to meet population needs. They do this by using indigenous crops selected for resistance to diseases, drought tolerance and many other desirable features, by intercropping and by integrating livestock management. In Worabe, farmers are maintaining a complex, sustainable and indigenous agricultural system that ensures food security. The system is based on *enset*, a very drought resistant, multiple-use indigenous crop.

Integrated production systems and diversified farms have helped farmers in south-central Chile reach year-round food self-sufficiency while rebuilding the land's productive capacity [94]. Small, model farm systems, consisting of polycultures and rotating sequences of forage and food crops, forest and fruit trees, and animals, have been set up. Soil fertility improved, and no serious pest or disease problems have appeared. Fruit trees and forage crops achieved higher than average yields, and milk and egg production far exceeded that on conventional high-input farms. For a typical family, such systems produced a 250% surplus of protein, 80 and 550% surpluses of vitamin A and C, respectively, and a 330% surplus of calcium. If all the farm output were sold at wholesale prices, a family could generate a monthly net income 1.5 times greater than the monthly minimum wage in Chile, while dedicating only a few hours per week to the farm. The time freed up can be used for other income-generating activities.

Organic agriculture can improve income, profitability and return on labour by removing or reducing the need for purchased inputs; by diversification (often adding a new productive element) and optimising productivity; by maintenance or improvement of on- and off-farm biodiversity, allowing farmers to market non-cultivated crops, insects, animals; and by sales on a premium market [148]. A case study from Senegal shows that yields can be increased manifold, and are less variable year on year, with consequent improvements in household food security. Likewise, a participatory fair-trade coffee cooperative in Mexico, which adopted organic techniques, allowed smallholder coffee growers to overcome soil degradation and low yields, and access a speciality market.

Money flows of an organic box scheme from Cusgarne Organics (UK) were examined to show the benefit of buying locally to the community at large [149]. The economic analysis followed the trail of the farm box scheme income, monitoring exactly where the money was spent, how much of it was ‘local’ expenditure, and then tracked that money to the next layer of spending. An estimate found that for every £1 spent at Cusgarne Organics, £2.59 is generated for the local economy. In contrast, a study involving Asda and Tesco found that for every £1 spent at a supermarket, only £1.40 is generated for the local economy. The study concludes, “The figures demonstrate that the net effect of spending at Cusgarne Organics to the local economy is nearly double the effect of the same amount spent with out-of-county and national businesses.” (p. 16).

Twenty-Four

Better Food Quality

A comprehensive review of scientific research shows that, on average, organic food is better for us than non-organic food [150]. First, it is safer, as organic farming prohibits pesticide use, so chemical residues are rarely found, while in contrast, non-organic food is likely to be contaminated with residues that often occur in potentially dangerous combinations. Second, it has better food value. The British Society for Allergy, Environmental and Nutritional Medicine states on the back cover of the report: “We have long believed the micronutrient deficiencies common in our patients have their roots in the mineral-depletion of soils by intensive agriculture, and suspect that pesticide exposures are contributing to the alarming rise in allergies and other illnesses”.

Research also suggests that pesticide exposure affects male reproductive function, resulting in decreased fertilising ability of the sperm and fertilisation rates [151]. Furthermore, members of a Danish organic farmers' association, whose intake of organic dairy products was at least 50% of total intake of dairy products, had high sperm density [152]. Sperm concentration was 43.1% higher among men eating organically produced food [153]. While there are recommended safety levels for pesticides, the UK government's own tests have shown that average residue levels on foods may be under-reported.

Additionally, organic food production bans the use of artificial food additives, such as hydrogenated fats, phosphoric acid, aspartame and monosodium glutamate, which have been linked to health problems as diverse as heart disease, osteoporosis, migraines and hyperactivity. The review [150] found that on average, organic food has higher vitamin C, higher mineral levels and higher phytonutrients - plant compounds that can fight cancer - in organic food. Tests with people and animals eating organic food show it makes a real difference to health, and alternative cancer therapies have achieved good results relying on the exclusive consumption of organic food. Animal feeding trials have demonstrated better reproductive health, better growth, and better recovery from illness.

Novotny has already brought these and many other health benefits of organic foods to the attention of the UK government [154, 155]. Among the issues raised are the hidden costs of conventional agriculture, for example, through the BSE crisis. No animal born and raised on an organic farm developed BSE in the UK.

Children may stand to benefit in particular from organic food. Scientists monitored preschool children in Seattle, Washington to assess their exposure to organophosphorus (OP) pesticide from diet [156]. The total dimethyl metabolite concentration was approximately six times higher for children with conventional diets than those with organic diets. The dose estimates calculated suggest that consumption of organic fruits, vegetables and juice can reduce children's exposure levels from above to below the US Environmental Protection Agency's guidelines, thereby shifting exposures from a range of uncertain risk to a range of negligible risk. The study concluded that consumption of organic produce could be a relatively simple way for parents to reduce children's exposure to OP pesticides.

A literature review of 41 studies and 1,240 comparisons [157] found statistically significant differences in nutrient content between organic and conventional crops, attributed primarily to differences in soil fertility management and its effects on soil ecology and plant metabolism. Organic crops contained significantly more nutrients -vitamin C, iron, magnesium and phosphorus - and significantly less nitrates (a toxic compound) than conventional crops. There were non-significant trends showing less protein in organic crops. However, organic crops were of a better quality and had higher content of nutritionally significant minerals, with lower amounts of some heavy metals compared to conventional ones.

Plant phenolics (flavonoids) are plant secondary metabolites thought to protect plants against insect predation, bacterial and fungal infection and photo-oxidation. This same class of plant chemicals has been found to be effective in preventing cancer and heart disease, and to combat age-related neurological dysfunctions. A recent scientific paper [158, 159] compared the total phenolic (TP) content of marionberries, strawberries, and corn grown by sustainable, organic, or conventional cultural practices. Statistically higher levels of TPs were consistently found in organically and sustainably grown foods as compared to those produced by conventional agricultural practices.

An earlier study comparing antioxidant compounds in organic and conventional peaches and pears had established that an improvement in the antioxidant defence system of the plants occurred as a consequence of organic cultivation practices [160]. This is likely to exert protection against damage of fruit when grown in the absence of pesticides. Hence organic agriculture, which eliminates the use of synthetic pesticides and chemical fertilisers, could create conditions favourable to the production of health-enhancing plant phenolics.

Twenty-Five

Conclusion to Part 3

Sustainable agricultural approaches can deliver substantial increases in food production at low cost. They can be economically, environmentally and socially viable, and contribute positively to local livelihoods. They are also better for health and the environment.

Because the true root cause of hunger is inequality amongst nations and peoples, any method of boosting food production that deepens inequality is bound to fail to reduce hunger. Conversely, only technologies that have positive effects on the distribution of wealth, income and assets can truly reduce hunger [4]. Fortunately, such technologies already exist in sustainable approaches to agriculture.

Agroecology, sustainable agriculture and organic farming work, not just for farmers in the developed world, but especially for farmers in developing countries. As the FAO review [92] shows, there is a good existing base to build and scale up efforts for both certified and non-certified organic agriculture. The technologies and social processes for local improvements are increasingly well-tested and established, and already delivering benefits in terms of increased productivity. The examples reviewed here are only a foretaste of the myriad successful experiences of sustainable agricultural practices at the local level. They represent countless demonstrations of talent, creativity and scientific capability in rural communities [91].

There is thus an urgent need to concentrate effort, research, funds and policy support on agroecology, sustainable agriculture and organic farming, particularly strengthening production by farmers themselves for local needs. The challenge is to scale-up and multiply the successes, as well as to make them equitably and broadly accessible. The model of modern agriculture, so often in the hands of a few large corporations, must be challenged, as must be GM crops. Existing subsidies and policy incentives for conventional chemical and biotechnological approaches need to be dismantled, and brakes must be applied on the drain of resources away from the alternatives [4]. We also need to guard against organic agriculture being taken over by powerful interests, and support all kinds of sustainable agriculture, especially that on small farms.

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Statement of the Independent Science Panel

Launched 10 May 2003, London.

The Independent Science Panel (ISP) is a panel of scientists from many disciplines and committed to the following.

1. Promoting science for the public good, independent of commercial and other special interests, or of government control

We firmly believe that science should be accountable to civil society, that it should be accessible to all, regardless of gender, age, race, religion or caste, and that all sectors of civil society should participate in making decisions on all issues related to science, from scientific research to policies regarding science and technologies.

We believe that accurate scientific information should be promptly accessible to the public in unbiased and uncensored forms.

2. Maintaining the highest standards of integrity and impartiality in science

We subscribe to the principles of honesty, openness and pluralism in the practice of science. There should be open peer review for published work, and respect and protection for those whose research challenges the conventional paradigm or majority opinion. Scientific disagreements must be openly and democratically debated.

We are committed to upholding the highest standards of scientific research, and to ensuring that research funding is not skewed or distorted by commercial or political imperatives.

3. Developing sciences that can help make the world sustainable, equitable, peaceful and life-enhancing for all its inhabitants

We respect the sanctity of human life, seek to minimise harm to any living creature, and protect the environment. We hold that science should contribute to the physical, social and spiritual well being of all in all societies.

We are committed to an ecological perspective that takes proper account of the complexity, diversity and interdependence of all nature.

We subscribe to the precautionary principle: when there is reasonable suspicion of serious or irreversible damage, lack of scientific consensus must not be used to postpone preventative action.

We reject scientific endeavours that serve aggressive military ends, promote commercial imperialism or damage social justice across the world.

The Genetic Modification Group of the ISP

The Genetic Modification (GM) Group of the ISP consists of scientists working in genetics, biosciences, toxicology and medicine, and other representatives of civil society who are concerned about the harmful consequences of genetic modifications of plants and animals and related technologies and their rapid commercialisation in agriculture and medicine without due process of public consultation and consent.

We find the following aspects especially regrettable and unacceptable:

- Lack of critical public information on the science and technology of GM
- Lack of public accountability in the GM science community
- Lack of independent, disinterested scientific research into, and assessment of, the hazards of GM
- Partisan attitude of regulatory and other public information bodies, which appear more intent on spreading corporate propaganda than providing crucial information
- Pervasive commercial and political conflicts of interests in both research and development and regulation of GM
- Suppression and vilification of scientists who try to convey research information to the public that is deemed to harm the industry
- Persistent denial and dismissal of extensive scientific evidence on the hazards of GM to health and the environment by proponents and by supposedly disinterested advisory and regulatory bodies
- Continuing claims of GM benefits by the biotech corporations, and repetitions of these claims by the scientific establishment, in the face of extensive evidence that GM has failed both in the field and in the laboratory.

- Reluctance to recognize that the corporate funding of academic research in GM is already in decline, and that the biotechnology multinationals (and their shareholders) as well as investment consultants are now questioning the wisdom of the 'GM enterprise'
- Attacks on, and summary dismissal of, extensive evidence pointing to the benefits of various sustainable agricultural approaches for health and the environment, as well as food security for farmers and the social well-being of local communities.

ISP-GM Group Review

We have undertaken an extensive review of evidence indicating that GM crops are neither needed nor wanted and that they have failed to deliver their promises; on the contrary, GM crops are presenting escalating problems for farmers and posing unacceptable risks to health and the environment.

At the same time, the success and manifold benefits of all forms of sustainable agriculture are no longer in doubt.

Consequently, we are demanding a ban on the commercial growing of all GM crops, and a comprehensive shift to agroecology, sustainable agriculture and organic farming.

A summary of the deliberations of the Independent Science Panel on GM is presented in, *The Case for A GM-Free Sustainable World*, Independent Science Panel, ISIS & TWN, 2003.

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