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Genetically-Modified Crops

The risks, benefits, theological questions and bioethical challenges posed by genetically-modified (GM) crops are reviewed. There is already much evidence that the increased intensity of UK farming since the 1960s is the most likely cause of the decline in abundance of several important farmland species of birds, butterflies and other taxa. Unless it can be shown incontrovertibly that the application of herbicide-tolerant GM crop management will lead inevitably to a reversal of this decline in biodiversity, to recommend commercialisation in an unrestricted fashion would be to relinquish the responsibility of stewardship given us in Genesis 2. To allow the current, steady decline in biodiversity to continue is no longer acceptable, theologically, bioethically or politically. Fortunately, whatever the outcome of the Farm Scale Evaluations, agro-ecologists can devise mandatory restrictions on GM crop management that ensure a positive benefit to biodiversity, for a relatively small yield penalty. Such systems might then act as paradigms for conventional agriculture, in which the farmer is the steward of the countryside. The need to increase food production in Third World countries is clear, but GM technology does not yet conform to goals of feeding the hungry, and requires changes in delivery to ensure equitability and sustainability.

Key-Words: GM crops; biodiversity; biotechnology; ecology; stewardship

1. Introduction

Much has now been written about genetically-modified, or GM crops from a Christian perspective.[1] Here, I review the theological aspects and consider the bioethical challenges of GM crops in the immediate future for UK agriculture. Some material in this manuscript has been abstracted from wider descriptions of issues relevant to GM crops in the UK since 1999.[2]

A GM crop plant is one that contains at least one transgene, from another plant of the same species or from a completely different species, inserted artificially instead of through pollination,[3] usually to enhance some beneficial

1 Burke, D. 'Genetically modified foods: why so much concern?', *Science & Christian Belief* (1999) 11, 2-4.
2 Perry, J.N. 'Genetically Modified Crops' (2001) in Beamond B., (ed.) *Genetic Engineering*, Lymington: Christ and the Cosmos Initiative, pp. 22-91; Perry, J.N. 'GM Crops and the Environment' (2003) in Ford, B.J. (ed.) *GM Crops, the Scientists Speak*, (Proceedings of the Cambridge Society for the Application of Research, Symposium on GM Food, Churchill College, Cambridge, 23 March 2002), Cambridge: Rothay House, Chapter 6.
3 Bryant, J. 'Introduction to Genetic Engineering' (2001) in Beamond B., (ed.) *Genetic Engineering*, Lymington: Christ and the Cosmos Initiative, pp. 11-21.

agronomic property. Most of those developed or proposed confer resistance to a herbicide (genetically-modified herbicide-tolerant, or GMHT), to an insect (e.g. genetically modified to express the insect toxin *Bacillus thuringensis*, or GM*Bt*) or to a plant viral pathogen. Other desirable traits conferred include salt or drought tolerance, and improved storage characteristics. Currently, the area planted with GM crops worldwide is 52.6 million hectares,[4] mainly in the USA, Argentina, Canada, China and Australia. Five million farmers, of whom three quarters are smallholders in China, are growing GM crops.[5] In North America, GM crops have been grown for some years, the USA area having increased about twenty-fold from the 1.7 million hectares planted in 1996. More than half of the world's soybean is now GMHT. Other major GM crops currently grown are: GM*Bt* corn and cotton, GMHT oilseed rape (OSR, termed 'canola' in North America), and GM virus-resistant potato, squash and papaya.

In Europe the risks posed by GM crops have been studied since the mid-1980s.[6] Successive UK Governments have used committees to assess the risks posed by GM crops since the late 1980s, firstly through the PROSAMO (planned release of selected and modified organisms) project,[7] and then via the Advisory Committee on Releases to the Environment (ACRE)[8] and the Advisory Committee for Novel Foods and Processes (ACNFP). These committees comprise mainly academic scientists, although for over ten years they have included consumer representatives and ethical advisers. Admittedly, in recent years the reputations of scientists in general for integrity have been damaged in the public mind and, once damaged, are difficult to recover. Yet I have witnessed personally how independent and scrupulous are the members of the ACRE and ACNFP committees. Their work engenders trust and deserves honour that we are encouraged as Christians to give where deserved (Proverbs 24:12; Romans 13:6-7). Since the mid-1990s, the bioethical issues involved have been studied by several bodies and individuals,[9] starting with the Government-sponsored Polkinghorne Committee,[10] which took evidence from Christians, Jews, Muslims, Hindus and Sikhs. A very substantial contribution to this debate was the Nuffield Council on Bioethics report: *Genetically Modified Crops: The Ethical and Social Issues*, that canvassed opinion from many groups

4 Conway, G. 'Regenerating the Green Revolution' (2002) in *GMOs – Ecological Dimensions*, (Proceedings of the meeting 9-11 September 2002 at the University of Reading), Wellesbourne: Association of Applied Biologists.
5 Huang, J., Rozelle, S., Pray, C., and Wang, Q. 'Plant biotechnology in China', *Science* (2002) 295, 6 74-677.
6 OECD. *Recombinant DNA safety considerations: Safety considerations for industrial, agricultural and environmental applications of organisms derived by recombinant DNA techniques*. Paris: OECD (1986).
7 Cherfas, J. 'Transgenic crops get a test in the wild', *Science* (1991) 251, 878.
8 ACRE *Advisory Committee on Releases to the Environment, Annual Report, No. 4, 1996/97.* London: DETR, HMSO (1998).
9 Straughan, R. and Reiss, M. *Ethics, Morality and Crop Biotechnology*, Swindon: BBSRC (1996).
10 Polkinghorne, J. *Report of the Committee on the Ethics of Genetic Modification and Food Use*, London: HMSO (1994).

in the UK, including faith representatives.[11]

In addition to contributions from non-governmental organisations (NGOs) and campaigning groups, there have been a number of analyses of specifically Christian issues raised by GM crops. These include studies by: The Science, Religion & Technology Project of the Church of Scotland,[12] The Evangelical Alliance,[13] The Environmental Information Network of Churches Together in Britain and Ireland, The John Ray Initiative, The Christ & the Cosmos Initiative[14] and Christian Ecology Link.[15] The Church of England, The Church of Scotland, The Methodists and the United Reformed Church have all published briefing papers on the subject.[16] The organisations Christian Ecology Link and Christian Aid took a particularly strong stance against GM crops[17] In June 2000, the Government responded to calls from the Nuffield Council on Bioethics[18] and other groups to set up a new body, The Agriculture and Environment Biotechnology Commission (AEBC), to provide a 'stakeholder forum' with a remit that includes advising Government on developments in biotechnology and their implications for agriculture and the environment by looking at the broad picture and taking into account ethical and social issues as well as the science. The AEBC has a very wide membership from both sides of the GM debate and includes a professor of bioethics and a professor of theology.

There are four major possible risks from GM crops: (i) the risk to human health through eating genetically modified food; (ii) genetic risks as a result of adverse or unforeseen events caused either by mobility of the transferred gene from the new GM crop variety into other species, or by invasiveness of the GM plant itself; (iii) indirect environmental impacts on the arable ecosystem and its associated wildlife, caused perhaps by effects on non-target species, or by changes in crop management associated with these new varieties; (iv) the socio-economic effects of commercialisation, particularly as it affects consumer choice, world poverty and Third-World farmers.

There are also specifically Christian concerns over GM crops: Is the manufacture of GM crop plants expressly forbidden in the Bible? Is such manufacture wrong because it usurps God's function in creating life? Do the ecological consequences conflict with our duty as stewards of the world and its environment? Will GM crops result in injustice to the poor? Should we acquiesce that

11 Ryan, A., Burke, D., Gale, M., Heap, B., Leith, P., Hill, J., *et al*. *Genetically Modified Crops: The Ethical and Social Issues*, London: Nuffield Council on Bioethics (1999).
12 Bruce, D. and Bruce, A. *Engineering Genesis*, London: Earthscan (1998).
13 Bruce, D, and Horrocks, D. (eds) *Modifying Creation?* London: Paternoster Press (2001).
14 Beamond, B. (ed.) *Genetic Engineering* (Volume XV of the consultations), Lymington: Christ and the Cosmos Initiative (2001).
15 Christian Ecology Link. *Should the Church of England allow trials of genetically modified crops on its land?*, Harrogate: Christian Ecology Link (July 1999).
16 Bruce and Horrocks *op.cit.*[13] Appendix 6
17 Simms, A. *Selling suicide*, London: Christian Aid (1999); Christian Ecology Link *op.cit.*[15].
18 Ryan, Burke etc. *op.cit.* [11]

our relatively privileged, affluent society is becoming ever more risk averse? In addition, for scientists, there are personal Christian issues. In an area of deep controversy (Ecclesiastes 12:12), often with bitter public debate, am I telling the truth or sacrificing objectivity for a particular campaigning viewpoint.[19] Am I fulfilling a duty to explain my actions and to provide transparent and impartial advice to all who seek it? How can I follow Jesus in reaction to those who vilify or traduce me, or interfere with my experiments? How do we balance responsibility to innovate with the realisation that safety is not guaranteed,[20] that chance plays some role in the world (Ecclesiastes 9:1) and that hazards are the necessary cost of a creation given the freedom by its Creator to be itself?[21] Have we the necessary humility (Colossians 3:12; 1 Peter 5:5) to realise that we make mistakes every day, the open-mindedness (Proverbs 15:31-2) to trap errors early and the patience (Hebrews 6:12) to assess risk (Proverbs, 14:16) honestly on behalf of others? These risks and questions cover a range of disciplines and encompass a complex set of issues. It is paramount to realise that GM crops are not 'a single question about which one is "for" or "against"'.[22]

The ACRE, ACNFP and UK Government approach to risk assessment is on a 'case-by-case' basis, where each application is assessed in depth according to the GM trait and the particular circumstances of the proposed release. Briefly, the current consensus scientific thinking over the first three of the four secular risks listed above appears to be as follows. Regarding food safety, the recent Royal Society report[23] continued to endorse cautiously further research and development of GM food. Another recent review, funded by the Rockefeller Foundation and carried out by the National Center for Food and Agricultural Policy of the USA (http://www.ncfap.org/pup/biotech/benefitsandrisks.pdf)[24] concluded that: 'it is clear … that extensive studies were conducted addressing these risks. In reviewing the safety of Roundup Ready soybeans, no indication of greater health or environmental risks were found compared to conventional varieties. The review of *Bt* corn shows that no indication of greater health or environmental risks were found.'

Genetic effects may be divided into vertical and horizontal gene transfer. With regard to vertical gene transfer, experiments to monitor invasiveness[25] of GM arable crop plants in the UK gave ACRE no cause for concern. The review

19 See e.g. Bruce and Horrocks *op.cit.* [13] pp15-16.
20 Bruce, D. 'Pollution'. in Beetham, P.A. (ed.) *Risk! Life is a Risky Business*, Lymington: Christ and the Cosmos Initiative (1999), section 6, pp. 47-74.
21 Polkinghorne, J. *Belief in God in an Age of Science*, New Haven: Yale University Press (1998).
22 Bruce and Horrocks *op.cit.* [13] pp.13,144.
23 The Royal Society. *Genetically Modified Plants for Food Use and Human Health – an Update*, London: The Royal Society (2002).
24 Carpenter, J.E. *Case studies in benefits and risks of agricultural biotechnology: Roundup ready soybeans and Bt field corn*, NCFAP, Washington (2001).
25 Crawley, M.J., Hails, R.S., Rees, M., Kohn, D., Buxton, J. 'Ecology of transgenic oilseed rape in natural habitats', *Nature* (1993) 363, 620-623; Crawley, M.J., Brown, S.L., Hails, R.S., Kohn, D., Rees, M. 'Transgenic crops in natural habitats', *Nature* (2001) 409, 682-683.

by Hails[26] stressed the different positions on the risk-assessment scale that the classes of current GM traits occupy (with herbicide-tolerance lowest risk, insect-resistance next and virus-resistance the greatest). For herbicide tolerance, she argued, on the basis of ecological fitness, that hybrid offspring resulting from crosses between weedy near-relatives of GMHT crops would enjoy no selective advantage in the wild and would therefore not be expected to cause problems in the absence of herbicide.

The argument proceeds as follows. Ecological fitness has a very precise meaning that can be quantified. First, choose one point in the life cycle of the plant in successive generations: seeds, seedlings, adult plants – the point chosen is immaterial. Next, estimate the ratio of the number of plants at this point in the next generation, divided by the number at the same point in the current generation. This ratio is termed the finite rate of increase; if it is greater than 1 the population will increase; if it is less than 1 the population will decline to extinction. In general, if there is no selective advantage conferred by the gene to the hybrid offspring of the GM plant with weedy near-relatives, then that ratio will be, on average, less than unity, and certainly no greater than that of non-hybrid weeds of the same species. Hybrids would therefore be no 'fitter' than the non-hybrids. There would then be no reason to suppose that those with the extra gene would outcompete those without it, and no reason, therefore, to expect that gene to establish or persist in the wild population. These results would be of no surprise to an ecologist, as it would not be expected that herbicide tolerance would confer any ecological advantage to a plant outside the agricultural habitat in which it is being sprayed with the herbicide. Indeed, there is much evidence that the carrying of such extra genes usually confers a fitness penalty, and often there is a trade-off: for example, aphids resistant to certain insecticides are less able to overwinter successfully.[27] Of course, if some other GM trait is considered, and the gene does confer some selective advantage, then the ratio may be greater than one and the gene may persist and spread into the wild population. This reinforces the need for the risk assessment of each crop-construct to be considered on a case by case basis. There is no evidence of superweeds in the UK, despite extensive GMHT trials.[28]

With horizontal gene transfer, there is less probability of harm, but potentially a greater hazard, and therefore more controversy. The ACRE position is

26 Hails, R.S. 'Genetically modified plants – the debate continues', *Trends in Ecology and Evolution* (2000) 15, 14-18.

27 Foster, S.P., Harrington, R., Devonshire, A.L., Denholm, I., Devine, G.J., Kenward MG, *et al*. 'Comparative survival of insecticide-susceptible and resistant peach-potato aphids, Myzus persicae (Sulzer) (Hemiptera: Aphididae), in low temperature field trials', *Bulletin of Entomological Research* (1996) 86, 17-27.

28 Firbank L. *Farm scale evaluations of GM crops: Effects of the management of field scale releases of genetically-modified herbicide-tolerant crops on the abundance and diversity of farmland wildlife: 6th Interim Report*. London: DEFRA (2002); Scott, S.E. and Wilkinson, M.J. 'Low probability of chloroplast movement from oilseed rape (*Brassica napus*) into wild *Brassica rapa*', *Nature Biotechnology* (1999) 17, 390-392; and see http://www.defra.gov.uk/environment/fse/index.htm).

that, although horizontal gene transfer from GM plants is theoretically possible, this would be an exceedingly rare event, even on an evolutionary timescale. Furthermore, unless there is very strong selection for the gene that is transferred, it will remain at a low frequency in the population at large; therefore selection pressure is again the key factor.

It was on this basis that ACRE recommended to Government that the third, and less-hazardous, danger of indirect, environmental harm to the arable ecosystem and its associated wildlife through the management of GM crops could be studied, outdoors, in the so-called Farm Scale Evaluations (FSE) of GMHT crops.[29] This most extensive trial of the effect of the commercialisation of GM crops in Great Britain was motivated by concerns raised in 1998 by the Government's advisers on nature conservation and wildlife, English Nature. They were worried that GMHT management would create an 'ecological wilderness', an arable ecosystem devoid of weeds, which would result in less food and cover for farmland insects and, indirectly, for bird species higher up the food-chain that feed on weed seeds and on those insects.

The increased intensity of farming had already been identified as the most likely cause of the decline of several important farmland bird species[30] and in biodiversity.[31] Other studies presented evidence[32] that the weeds in GMHT crops that are allowed to persist longer than in conventional systems may provide food resources and habitat structure during a critical part of the year for insects and nesting birds. It is important to realise that the FSE does not address the food safety or genetic risks described above, nor the socio-economic aspects. Specifically, the primary null hypothesis of the experiment is that there is no difference between the abundance and diversity of farmland wildlife under GMHT management and that pursued in current conventional farming. The rationale for the baseline of current conventional farming has been addressed in detail[33] as has the absence of an organic component.[34] The wildlife recorded are key indicators of biodiversity including: vegetation, gastropods,

29 AEBC. *Crops on Trial*. London: DTI (2001); Firbank, L. *op.cit.*[28]; Firbank, L.G., Heard, M.S., Woiwod, I.P., Hawes, C., Haughton, A., Champion, G., *et al*. 'An introduction to the Farm Scale Evaluations of genetically modified herbicide-tolerant crops', *Journal of Applied Ecology* (2003) 40, 2-16; Perry, J.N., Rothery, P., Clark, S.J., Heard, M.S., Hawes, C. 'Design, analysis and power of the farm-scale evaluations of genetically-modified herbicide-tolerant crops', *Journal of Applied Ecology* (2003) 40, 17-31.

30 Krebs, J., Wilson, J.D., Bradbury, R.B., Siriwardena, G.M. 'The second Silent Spring?', *Nature* (1999) 400, 611-612.

31 Robinson, R.A. and Sutherland, W.J. 'Post-war changes in arable farming and biodiveristy in Great Britain', *Journal of Applied Ecology* (2002) 39, 157-176.

32 Dewar, A.M., Haylock, L.A., Bean, K.M. and May, M.J. 'Delayed control of weeds in glyphosate-tolerant sugar beet and the consequences on aphid infestation and yield', *Pest Management Science* (2000) 56, 345-350; Dewar, A.M., May, M.J., Woiwod, I.P., Haylock, L.A., Champion, G.T., Garner, B.H. *et al*., 'A novel approach to the use of genetically modified herbicide tolerant crops for environmental benefit', *Proceedings of the Royal Society B* (2003) 270, 1513.

33 See Firbank, Heard etc. and Perry, Rothery etc. *op.cit.* [29].

34 Perry (2003) *op.cit.* [2].

invertebrate pests, beetles, spiders, Heteroptera, detritovore Collembola, other invertebrates, bees and butterflies. The risks will be assessed from late-2003, when the results are made public. A further example of a potential indirect effect[35] came from a laboratory toxicity study[36] of the effect of pollen from GM*Bt* corn on larvae of the Monarch butterfly, although ecological studies outdoors in North America have agreed that the actual field-scale effects on Monarchs is slight.[37]

It is impossible to argue that such a consensus exists with regard to the socio-economic risks, because these are less liable to experimental verification and more open to controversy. Consider, for example, the Green Revolution. On the one hand organizations such as Greenpeace and Christian Aid claim that the adoption of intensive agricultural practices has forced millions of subsistence farmers from the land into the cities.[38] On the other hand it is claimed[39] that the lives of millions of city dwellers have been saved by a large and sustainable increase in food production which would otherwise have involved ploughing up of millions of hectares of wilderness and forest.[40] Such issues are covered in considerable detail in many studies.[41] Questions asked include: How do GM crops fit into our desire to farm sustainably, to pass on to future generations a healthy and whole environment and to act as responsible and good stewards (Genesis 2:15)? Will GM crops be used to alleviate poverty or to exacerbate it, to distribute resources equitably (Isaiah 58: 6-11) or to concentrate them (Isaiah 3:15), to empower farmers or to control them (Isaiah 33: 6-8), to deliver choice or to restrict it? Are GM crops the answer to the coming crisis of overpopulation, or an irrelevance in the light of inequitable distribution (Deuteronomy 15: 1-15) and an example of the worst aspects of globalisation linked to unfair rules of world trade? Is the commercial exploitation of GM crops inextricably linked to gene patenting and biopiracy or does it simply represent the need for a fair return on research investment? Some questions will

35 for a short review see Poppy, G.M. 'GM crops: environmental risks and non-target effects', *Trends in Plant Science* (2000) 5, 4-6.

36 e.g. Losey, J.E., Rayor, L.S. and Carter, M.E. 'Transgenic pollen harms Monarch larvae', *Nature* (1999) 399, 214.

37 Hellmich, R.L., Siegfriend, B.D., Sears, M.K., Stanley-Horn, D.E., Daniels, M.J., Mattila, H.R., *et al*. 'Monarch larvae sensitivity to *Bacillus thuringiensis*-purified proteins and pollen', *PNAS* (2001) 98, 11925-11930.

38 Shiva V. *The Violence of the Green Revolution*, Penang: Third World Network (1991).

39 Ridley M. *Comment: The poverty of Reith Lecturer's thinking*. London: Daily Telegraph (16 May 2000).

40 Trewavas, A.J. 'The population/biodiversity paradox; agriucltural efficiency to save winderness', *Plant Physiology* (2001) 125, 174-179.

41 Heap B. 'GM crops and the Third World – Ethical Considerations' (2003) in Ford, B.J. (ed.) *GM Crops, the Scientists Speak*, (Proceedings of the Cambridge Society for the Application of Research, Symposium on GM Food, Churchill College, Cambridge, 23 March 2002), Cambridge: Rothay House; Conway, G. 'Crop Biotechnology: Benefits, Risks & Ownership' (2000) in *GM Food Safety: Facts, Uncertainties and Assessment*, (Proceedings of the meeting 28 February – 1 March 2000, Edinburgh), Paris: OECD; and see Burke *op.cit.* [1]; Ryan, Burke etc. *op.cit.* [11]; Bruce and Horrocks *op.cit.* [13]; Simms *op.cit.* [17]; AEBC *op.cit.* [29].

increase in importance very shortly in the UK if a decision is made to allow the commercialisation of GM crops. These include: Can there be co-existence between conventional, GM and organic agriculture? What constitutes 'harm' and who is ethically and legally responsible for perceived or actual harm caused by or done to GM crops? What mitigating measures could or should be used to redress harm? I return to these important issues in section 4.

2. Conflicts over agriculture in the Bible

It is impossible to consider theological aspects of GM crops without placing the issues introduced above in the context of the central role played by agriculture in the Bible, especially in Genesis. Our transition from hunter-gatherers to farmers, through a nomadic phase, clearly caused much conflict and tension. The hunter-gatherer phase was authorised by God (Genesis 1: 29), although in Genesis 2:5 the transition to agriculture is anticipated before God created Man. Hunter-gatherers may affect their environment and the distinction between this and farming is not always easy to discern. This need to take action, to intervene and manage, even prior to farming, is implied in God's command to tend the Garden in Genesis 2:15. Indeed, Tudge[42] has described a form of proto-farming, involving just plant protection and propagation, prior to tillage and not recognisable as agriculture, in which unconscious human-induced selection pressure may have had profound effects on the genetics of favoured plants or animals.

The first-mentioned of Adam's punishments, following the Fall, involves a wrench from the relatively easy form of provision of food in the Garden to a struggle to extract a living, where 'By the sweat of your brow you will eat your food.' The consequences are described graphically in terms of the sheer hard slog of farming (Genesis 3:17-19), and weeds are described for the first time. Of course, one would hesitate to describe those who retained a largely hunter-gatherer existence as living in some Edenic state. But could it be that the writer of Genesis drew on collective human unhappiness at the recollection of the replacement of a previous carefree, instinctive mode of providing for sustenance by a self-aware, planned, restrictive and intensive way of life? Dr Juris Zarins of Southwest Missouri State University has speculated whether the location for Eden lies under the current Persian Gulf in a fertile plain subsequently flooded following the end of the last Ice Age.[43] Tudge conjectured that if that was so, then the need for increased food production that followed this flooding, to support the subsequent increase in density in a population forced to flee to higher ground, might have forced a transition from hunter-gathering

42 Tudge, C. *Neanderthals, Bandits and Farmers – how agriculture really began*. London: Weidenfield & Nicholson (1998).
43 Hamblin, D.J. 'Has the Garden of Eden been located at last?', *Smithsonian Magazine* (1987) 18(2).

to more productive agriculture.

Another contrast, between a nomadic, pastoral existence and arable farming, is depicted immediately after the Fall (Genesis 4: 2-5), where Abel kept flocks while Cain worked the soil: the Lord looked with favour on Abel and his offering, but on Cain and his offering he did not. The punishment for Cain's murder of Abel again included a reference to ground that would no longer yield abundant crops when tilled. Noah, Adam's descendent through his son Seth, had a name that meant 'relief from the hard work of farming the ground' (Genesis 5:29), and God's covenant with him included the promise that there would always be a cycle including springtime and harvest (Genesis 8:22). The patriarch Abraham was called out of a city to be a pastoral nomad; like his children and grandchildren, Abraham lived in a tent (Genesis 18:1). Many writers[44] have noted that nomadic people took God with them and developed monotheism more naturally than did settled rural farmers or city dwellers who tended to be animistic or pantheistic, and worshipped objects on earth such as rocks, trees, or rivers.

God commanded the Hebrews, on entering the promised land of Israel, to remember always that they were all descended from a single wandering Aramean (Deuteronomy 26:5). In the books of the Pentateuch the Children of Israel are given, through Moses, very detailed laws concerning farming and crops (e.g. Leviticus 19, 23, 25), with the proviso that commandments should be kept if the land was to yield plenty (Deuteronomy 28), despite the fact that as a nation they had at that time never yet settled in one place or practised agriculture, except perhaps when as slaves in Egypt. To pass, as they did, from nomadic wanderings to settled residence, from the exclusive tending of herds to the culture of crops, from tents to farms in villages and thence to walled towns, involved a profound change in the life and thought of the people, not least in their religion.

In the New Testament, we find that it was shepherds, not farmers, that were called by the angel of the Lord to honour the birth of Jesus (Luke 2: 8-12), and later our Lord describes himself as 'the good shepherd' (John 10:11-14; Matthew 26:31; Zechariah 13:7; 1 Peter 5:4). Instructions such as 'do not worry about your life, what you will eat' and 'look at the birds of the air; they do not sow or reap or store away in barns, and yet your heavenly Father feeds them.' (Luke 12: 22-30; Matthew 6:25-34) seem the very antithesis of the role of the farmer, with its careful planning, investment of present time for future profit and binding to a particular piece of land.

The conclusion of this section is that farming does indeed play an important role in the Bible. However, I would tentatively speculate that there seems some evidence that the arable form of agriculture appears not to be viewed with as

44 e.g. Hunter, M.J. 'The Nomadic Church: The Church in its simplest form'. *International Journal of Frontier Missions* (2000) 17, 15-18.

much favour as we would perhaps expect. If true, this is disturbing for those of us whose work is in this area. Is it any wonder then, that in our own time, we continue to face ethical arguments about agriculture, concerning the effects of intensive farming on biodiversity, that challenge the way we interpret stewardship? But, however much we would all like to go back to a slower time, we need arable agriculture as a tool of our compassion, to produce food for a hungry world.

3. Theological concerns

3.1 Is the manufacture of GM crops explicitly forbidden in the Bible?

This is one of many modern challenges that could not have been conceived explicitly at the time that the Bible was written. Perhaps the closest the issue is to being addressed is within the cultic laws intended to avoid 'boundary-crossing' and to keep the Children of Israel a separate race, often for reasons of health, purity or cleanliness. 'Do not mate your cattle with a different kind; don't sow your field with two kinds of seed' (Leviticus 19:19; Deuteronomy 22:9-11).[45]

The degree to which pentateuchal laws are observed by modern Jewish people varies; for example burnt offerings and stoning have fallen into disuse. The particular issue of GM crops seems not to present a problem for the Office of the Chief Rabbi of the UK[46] with regard to the dietary laws, which form a major part of modern Jewish observance. Indeed, an article during the autumn of 2000 by Rabbi Rashi Simon and Professor Edward Simon in the *Jewish Chronicle*, explains in considerable detail why GM food *is* considered kosher. It is argued that even if the act of genetic modification of the original DNA were forbidden, and they maintain that it is not, the resulting plants would still be kosher because, as is often unappreciated, the event of genetic transformation happens only once. After the initial GM plant is generated, all subsequent seed used is manufactured through the perfectly standard crossing techniques of plant breeding. However, it is of course possible that there might be a problem were any novel GM crop to contain a porcine gene. In any event, for Christians, this class of cultic law was rendered immaterial by Jesus' own actions (Matthew 15:22-8; Matthew 8:5-13; John 4:7-42) and by the promptings of the Holy Spirit to Philip (Acts 8:26-38) Peter (Acts 10, 11:1-18) and, later, Paul (Acts 13:46-7). Hence there appears no explicit biblical restriction on the manufacture of GM crops.

45 See Perry (2001) *op.cit.* [2] and Bruce and Horrocks *op.cit.* [13].
46 See Polkinghorne *op.cit.* [10] and Ryan, Burke etc. *op.cit.* [11] section 1.38.

3.2 Does the manufacture of GM crops usurp God's function as Creator of life?

Proponents of biotechnology often put forward the case that GM techniques are but a small extension of what has gone before and that they therefore need no special ethical defence. They cite a sequence of techniques developed over the past 150 years, which gradually pushed at the boundaries of between-species reproduction, until 1983, when the first genetically-modified tobacco plant was formed. By 1880, first interspecific and then intergeneric crossing led to Triticale, a wheat × rye cross now grown on 2 million hectares. By 1910, protoplast fusion was reported; by 1930, mutagenesis via X-rays yielded Golden Promise barley, a constituent of the great majority of our fine English beers. By 1940, we had polyploidisation; by 1970, the ability to cross between any two species within the grasses by embryo hybrid rescue. This is informative, but in my view unhelpful in answering our question. The fact that something was wrong some time ago does not make a similar thing proper now, nor does it prevent a small step from marking the change from what is acceptable to what is unacceptable.

The argument concerning whether we are 'playing God' by manufacturing GM crops revolves round the question whether species barriers are immutable or somehow sacrosanct. As scientists, most of us subscribe to Darwinian notions of evolution.[47] Most population ecologists would admit to difficulty in defining precisely what they mean by a population, and similarly many biologists would contend that species boundaries are actually indistinct and difficult to define easily.[48] Davies[49] explains how Darwin's concept of a population of different individuals stresses the uniqueness of every living thing in the world (cf. Luke 12:7; Psalm 139:1-18) and how Darwin viewed the species as a statistical abstraction. By contrast, Davies traces back to Plato and Aristotle the view of a species as an unchangeable type with a 'defining essence'. He believes that the Platonic view of 'eternal and ideal forms', doctrinal for over 2000 years, is still deeply ingrained within our collective psyche. He argues that because of this 'it is not surprising that many people today find the mere thought of taking a gene from one species and placing it in another as abhorrent' and perhaps that is also the reason why this repugnance baffles some scientists.[50]

The challenges to Christianity during the nineteenth century from the new ideas of Darwin regarding evolution, selection and fitness have been well documented.[51] We may believe that this debate is over and that any conflicts have been resolved. Davies challenges this, because he claims that most people, irre-

47 Brooke, J.H. 'The Wilberforce-Huxley Debate: Why Did It Happen?' *Science & Christian Belief* (2001) 13, 127-141.
48 Straughan and Reiss *op.cit.* [9].
49 Davies, K. 'What makes genetically modified organisms so abhorrent?' *Trends in Biotechnology* (2001) 19, 424-427.
50 Ryan, Burke etc. *op.cit.* [11].
51 Brooke *op.cit.* [47].

spective of faith, even though they may accept the weight of evidence in favour of evolution, have nevertheless not taken on board the implication that species are fluid and difficult to define, a notion at odds with the popular classical concept that they are well-defined and changeless. Is it possible that for many Christians this issue still needs to be faced before we can fully resolve Darwinian evolution with our theology? Antisthenes is reported to have challenged the Platonic idea thus: 'I can see a horse, Plato, but I cannot see horseness.' In a similar vein, Popper[52] asked: 'Why cannot there be as many "essences" in things as there are things?' Antisthenes' and Popper's questions might be thought to reflect our Christian belief in human uniqueness, in a way that it is extended to include all life forms. It is also relevant for the GM debate that genome maps have taught us that many very similar genes are shared in common among unrelated species.[53]

We have to ensure a proper balance between our need to practise agriculture and improve yields and our responsibility to exercise a benevolent, kingly care of creation as expressed in Genesis 2. Much has been written concerning the concept of stewardship, in this regard, by Professors Sam Berry[54] and Sir Ghillean Prance.[55] They argue that the effects of the technology and the use to which it is put are the crucial issues, not the technology itself. We are called to act creatively, reflecting the creativity of God in whose image we are made, so long as our use of the technology is wise and ethical. Therefore we must ensure that our freedom actively to mould creation to our needs through GM crops does not unduly harm the environment, and is used to help feed the hungry (Proverbs 3:27, Isaiah 3:14-15, Amos 2:6, Matthew 5, 6, 25:14-25). My reason for using the vague word 'unduly' here is that I wish to emphasise the need to be cautious when making claims about the effects of agriculture on the environment. Dr Les Firbank in his evidence to the AEBC[56] stressed the importance of talking about 'impact' rather than 'harm', the latter being difficult to define. He rightly stressed the need to account for the resilience of an ecosystem to return to an equilibrium after perturbation and the need to take into account population-dynamic concepts such as density-dependence of effects, the buffering of effects, etc. Trewavas[57] is one of many who has proposed that, although intensive agriculture on appropriate land may harm biodiversity locally, it prevents more land of marginal agricultural value being ploughed up

52 Miller, D. (ed.) *A Pocket Popper*, London: Fontana (1983).
53 e.g. those that promote resistance to fungal infection, see Lander, E.S. *et al*. 'Initial sequencing and analysis of the human genome', *Nature* (2001) 409, 860-921.
54 Berry, R.J. *Sustainable development: Can it be made to work in the real world?*, Cheltenham: John Ray Initiative (2000); *The care of creation*, Leicester: IPV (2000); 'Creation and the environment', *Science & Christian Belief* (1995) 7, 21-43.
55 Prance, G. 'Preserving Biodiversity – Is there a Biblical reason?' in *Science, Religion & Society, Contemporary Perspectives*, Cambridge: CIS/St Edmunds Lecture Series (2002); http://www.st-edmunds.cam.ac.uk/cis/prance/index.html.
56 AEBC *op.cit.* [29].
57 Trewavas *op.cit.* [40].

to produce the same amount of food, and thereby is of net benefit to wilderness areas. Nevertheless, the negative effects of conventional intensive agriculture in the UK are known[58] and we cannot take our responsibilities of stewardship seriously without facing them honestly. Indeed, the Fall[59] reminds us of the need to approach the subject area humbly, warns of the dangers of overreaching ourselves and cautions us to spend sufficient time and energy in assessing the risks of GM crops before taking action.

Many have written of the folly of criticism that accuses biotechnology of being unnatural[60] (James 3:12) or explicitly of 'going against Mother Nature'. There are associated problems for Christians of arguments based on the new-age, neo-pagan approach, which worships creation instead of the Creator.[61] Prince Charles' twin errors[62] are firstly, to misunderstand that agriculture is by definition interventionist (Matthew 21:19) and, secondly, to dichotomise science and faith. Many Christians with scientific associations were quick to rebut his dismissal of scientific rationalism.[63] This view may manifest itself as a rejection of the reductionist bedrock on which the techniques of modern biological science are grounded, in favour of a deliberately less-rational, 'holistic' view of nature. Burke[64] has rejected both this postmodern view that the scientific process is partially subjective and irrational, with empirical evidence playing, at best, a subordinate role, and the equally erroneous adulation of science. He has suggested that the proper Christian response should be not to fear the discoveries of science, for what we discover is God's handiwork in the first place.

Some criticisms of reductionism by bioethicists[65] have erected a straw man, through a fundamental misunderstanding of its use in modern ecology. Ecologists study the holistic nature of the natural world, and are concerned primarily with the interconnections and complexity of real processes in nature, but they do so using tools that are essentially reductionist. Our detailed knowledge of whole-organism community population dynamics, food webs and multitrophic interactions is based on experimental data concerning individual components of systems, but knitted together at suitable scales, into an overarching conceptual framework underpinned by mathematical models. Such systems, built by quantitative biologists using reductionist techniques, have provided considerable insights, such as a greatly improved understanding of the epi-

58 Krebs, Wilson etc. *op.cit.* [30].
59 Berry, R.J. 'Discussing the Fall', *Science & Christian Belief* (1999).
60 Ryan, Burke etc. *op.cit.* [11] sections 1.32-1.40.
61 Bruce and Horrocks *op.cit.* [13].
62 Charles, Prince of Wales *A reflection on the 2000 Reith Lectures*. London: BBC (2000); www.princeofwales.gov.uk/speeches/environment_18052000.html.
63 e.g. Perry *op.cit.* [2].
64 Burke, D. 'BSE, MMR and GM: who's telling the truth?' in *Can we be sure about anything? Questions of truth in Science and Christianity* (Proceedings of the 29 September 2001 CIS Conference), London: CIS (2001).
65 Bruce and Horrocks *op.cit.* [13] pp.48-49.

demiology of infectious diseases such as AIDS, measles, bovine spongiform encephalopathy (BSE) and variant Creutzfeldt-Jacob disease (vCJD).[66] All theoretical ecologists would agree that the synthesis of the individual components is obligatory within their models, but the essential point is that this is done through study of the components and their interactions individually. Indeed, the argument that organic agriculture is not susceptible to reductionist, scientific study because it represents some holistic, interconnected system that works 'magically' is dangerous and unchristian nonsense. It is unsustainable if we are to understand, or even to monitor satisfactorily, the processes operating within the system.[67] For example, many ecologists suspect that most wildlife benefits in organic systems accrue because of spring planting and the management of field boundaries and margins, neither of which is intrinsically 'organic' and both of which may be adopted equally by conventional agriculture.[68]

My conclusion from this section is that, while the manufacture of GM crops is not immediately debarred as an unwarranted usurping of God's function as Creator of life, we must nevertheless strictly ensure that their use does not unduly harm the environment, and that they are used to alleviate hunger, sickness or poverty. These issues are addressed in the next section.

3.3 Does the use of GM crops have consequences that must of necessity be outside God's will?

The environmental impact of GM crops is both direct and indirect. Recall the warning,[69] above, of the direct effects, and of the gradation of risks from the relatively neutral herbicide-tolerant GM crops, through insect-resistant, to the plant virus-resistant. There is currently no evidence that the use of GMHT crops is hastening the serious problem of herbicide resistance[70] found, for example, in populations of some pernicious weeds such as *Alepocurus myosuroides*.[71] I do not regard gene-stacking[72] in offspring of different GMHT crops lightly, but it is an agronomic, not an environmental, problem, and one that is commonly faced by growers worldwide.

The second trait, that of insect resistance, requires careful management

66 Anderson, R.M. and May, R.M. *Infectious Diseases of Humans: Dynamics and Control*, Oxford: Oxford University Press (1991).
67 MacKerron, D.K.L., Duncan, J.M., Hillman, J.R., MacKay, G.R., Robinson, D.J., Trudgill, D.L., *et al*. 'Organic Farming: Science and Belief' in *1998-1999 Annual Report of the Scottish Crop Research Institute*. Invergowrie: Scottish Crop Research Institute (2000) pp. 60-72.
69 Trewavas, A.J. 'Urban myths about organic agriculture', *Nature* (2001) 410, 409-410.
70 Hails *op.cit.* [26].
70 Orson, J. 'The cost to the farmer of herbicide resistance', *Weed Technology* (1999) 13, 607-611.
71 Moss, S.R. 'The production and shedding of *Alopecurus myosuroides* Huds. seeds in winter cereal crops', *Weed Research* (1982) 23, 45-51.
72 Orson, J. 'Gene stacking in herbicide tolerant oilseed rape: lessons from the North American experience (English Nature Report No. 443)', Peterborough: English Nature (2002).

because of the danger that the pest populations for which the crop is engineered may themselves develop resistance to the pesticide, a problem that is particularly serious in Third World agriculture.[73] GM crops with this trait have the advantage of potential specificity to a narrower range of insects than current pesticides can target. For example, the toxin *Bacillus thuringensis* (*Bt*), licensed for use by organic farmers, is specific to Lepidoptera. In the USA, GM*Bt* cotton is grown with refugia to minimise the development of pest resistance, but this involves a small yield penalty and whether the infrastructure exists for such schemes to operate efficiently in Third World countries is questionable. Notwithstanding, the use of GM*Bt* cotton has resulted in 1.2m kg less pesticide being applied, 15m fewer applications worldwide,[74] an 80% reduction in usage in China, and a subsequent increase in non-target insects.

Development of virus-resistant (GMVR) GM crops has been less rapid. Here, there is a potential hazard because if there were hybridisation of GMVR crops with weedy near-relatives, these non-crop plants would have a selective advantage. Relatively little is known of the degree to which viral disease is a key factor in weed population regulation, but in certain cases the effect might be large,[75] and the effects more severe in the Third World. Again we see that we must be careful to evaluate each potential crop and variety on a case-by-case basis. For the immediate question of whether to commercialise herbicide tolerant crops within the UK and Europe, I would argue that direct effects present few problems for the environment.

Regarding indirect effects on the environment, the situation is more complex and offers grounds for greater caution. Admittedly, in the USA the use of GMHT soybeans has resulted in 19m fewer applications of herbicide, less runoff, an increased diversity of agronomic rotations available, a doubling in the acreage on which beneficial no-tillage agriculture is practised, consequent reductions in erosion, reduced fuel usage, and increased abundance of farmland birds.[76] Similar claims are made from small-scale trials of UK GMHT sugar beet.[77] However, full evaluation for the UK must await the interpretation of the results of the FSE in mid-2003. The specificity mentioned above for GM*Bt* is not present in current GMHT crops, which adopt broad-spectrum herbicide management.

The question is made more difficult because: (i) as stated above, it is not easy to measure ecological harm, and indeed, 'impact' is a better term to describe what studies like the FSE try to measure.[78] This is because effects may be

73 Denholm, I. and Devine, G. 'Insecticide resistance' in Levin, S.A. and Colwell, R., (eds) *Encyclopedia of Biodiversity*, London: Academic Press (2001) pp. 465-477.
74 Conway *op.cit.* [4].
75 Hails *op.cit.* [26].
76 Conway *op.cit.* [4].
77 Dewar, A.M., May, M. and Pidgeon, J.D. 'Management of GM herbicide-tolerant sugar beet for potential environmental benefit to farmland birds' in *IACR Annual Report 2001-2002*, Harpenden: Institute of Arable Crops Research (2002) pp. 44-47.
78 AEBC *op.cit.* [29]section 154.

reversible, limited in spatial and temporal extent, and may affect parts of the life-cycle that would be regulated in any event by other density-dependent mortality factors such as parasitism, if the effect under study were not present. No measure of absolute abundance is meaningful without the context provided by some such point of comparison as the amount expected under conventional agriculture or in some defined habitat; (ii) biodiversity is a wide, all-encompassing term, and any study can only measure a small range of species, chosen for their value as indicators of environmental change and convenience of recording;[79] (iii) because in ecological experiments it is difficult to control the variation of more than one or two factors, and expensive or impractical to work on a suitably large scale:[80] results from studies require detailed interpretation, often involving mathematical models, before they can be used confidently.

All these difficulties caution us to place in context the indirect effects of GM crops. For example, the importation of alien weeds such as *Fallopia japonica*, the Asian knotweed, often through garden centres rather than by agriculture,[81] will almost certainly have a far greater ecological impact than the release of any GMHT crops. However, despite these complexities, we now know with certainty that conventional intensive agriculture in the UK has led to decreases in numbers of a whole range of taxa, including weeds, invertebrates, birds and their habitat, over the last fifty years.[82]

I therefore argue in section 4 below that a decision to continue that process by adopting any new GMHT system that was merely 'no more or less harmful than conventional intensive agriculture' would not be in keeping with our responsibilities as stewards set down in Genesis 2. However, I then go on to show how this could be ameliorated through intelligent and creative farm management.

Regarding the wider socio-economic issues, the need for GM crops becomes yet more controversial. World agricultural production cannot with present technology keep pace with the food requirements of an exponentially growing world population that will reach 8 billion by 2020.[83] GM traits especially useful for less-developed countries include those discussed above, and also improved food quality, drought and saline tolerance, ability to fix nitrogen, and improved storage. However, because of the high capital cost of developing and registering a new crop type, it is only a handful of multi-nationals with suffi-

79 Firbank, Heard etc.; Perry, Rothery etc. *op.cit.* [29].
80 Perry, Rothery *op.cit.* [29].
81 Lee, W.G. 'Introduced plants, negative effects of' in Levin, S.A. and Colwell, R. (eds) *Encyclopedia of biodiversity*, London: Academic Press (2001) pp. 501-515.
82 Chamberlain, D.E., Fuller, R.J., Bunce, J.C., Duckworth, J.C. and Shrubb, M. 'Changes in the abundance of farmland birds in relation to the timing of agricultural intensification in England and Wales', *Journal of Applied Ecology* (2000) 37, 771-788; Krebs, Wilson etc. *op.cit.* [30]; Robinson and Sutherland *op.cit.* [31].
83 Conway, G. and Toenniessen, G. 'Feeding the world in the twenty-first century'. *Nature* (1999) 402 (Supp: c55 – c58); Heap *op.cit.* [41].

cient resources that have developed commercial varieties thus far. As a result of too strong a desire to protect their intellectual property rights (IPR), some of these corporations have, rightly or wrongly, given the impression that they are bullying the weak, an action deplored by Christians (Micah 2:1-2). One example of this is the legal battle between the Monsanto company and small farmer Percy Schmeiser, from Bruno, Saskatchewan, Canada. According to Schmeiser,[84] his uncontested evidence was that he had never purchased Roundup-Ready Canola nor signed a technology-use agreement. He was found guilty in the Federal Court of violating Monsanto's patent on herbicide-resistant canola as a result of contamination, because he had Monsanto's genetics on his land and had not advised Monsanto of this so that they could redeem it. Schmeiser points out that he was not found guilty of obtaining the seed fraudulently, since all such allegations were dropped at the actual hearing, from lack of evidence. He has been recently granted leave to appeal to the Supreme Court of Canada.

The question of liability in the UK is an issue that the AEBC is currently studying. A related concern is that of biopiracy[85] by large corporations. It is important to distinguish between protecting the investment of time and money in research and the theft of life which belongs to God our Creator and is not ours to buy or sell (Leviticus 25:23). The controlling power of the seed industry has become largely consolidated into just five companies, and many people have expressed serious doubt as to whether this concentration of power can be a force for good. There is no reason in principle why the GM approach cannot be made to fit in with our goal of sustainability,[86] but this will require more imagination than currently shown by some of the large multinationals.

In particular, the ability of subsistence farmers to propagate their own crops and to save seed must be protected.[87] Yet GM biotechnology should not be identified solely with industry. The basis of the technology was laid in universities and publicly-funded agricultural research institutes, and considerable programmes at the forefront of molecular biology continue there. In the Tropics the publicly-funded CGIAR (Consultative Group on International Agricultural Research) group of institutes, such as CIMMYT (The International Maize and Wheat Improvement Center) and IRRI (International Rice Research Institute), all have plant-breeding programmes devoted to Third World applications, in tissue culture and marker-aided selection, as well as in GM. We need to remember that some tropical parasitic weeds, such as *Striga* and *Orobanche*, are so pernicious that they can completely destroy the crop of subsistence farmers. Over 1,000 biotechnologists are working in laboratories throughout Asia,

84 see http://www.percyschmeiser.com/.
85 Spinney, L. *Biotechnology in Crops: Issues for the developing world*. Oxford: Oxfam (1998).
86 Patten, C. 'On governance', *First 2000 Reith Lecture*. London: BBC (2000); Heap *op.cit.* [41].
87 Biotechnology and Biological Sciences Research Council. *Annual Report and Accounts, 2001-2002*. The Stationery Office, London: Biotechnology and Biological Sciences Research Council (2002).

mainly on GM rice varieties; over 100 GM events are being researched in China alone. By the end of the millennium there were over 10,000 field trials in thirty-nine countries.[88] Furthermore, there are many varieties of GM crops engineered to deliver health benefits, such as the so-called 'Golden' or vitamin-A GM rice[89] and bananas that express vaccines against cholera or hepatitis. The delivery of Golden rice was made difficult through the need to obtain permission from thirty-two companies and universities to use seventy different processes or materials. Thanks to public pressure there was much goodwill in the leading companies to come to an agreement on the use of IPR for humanitarian use that does not interfere with commercial interests, although the process took a full year. Early in 2001, the Rockefeller Foundation announced that five major companies had donated key intellectual property licenses: Syngenta Seeds AG, Bayer AG, Monsanto Co. Inc., Orynova BV and Zeneca Mogen BV. Freedom-to-operate licenses have been granted to public research institutions in developing countries to proceed with introducing the GM trait into local rice varieties. The major project is located at IRRI, under Dr S.K. Datta.[90]

A possible resolution of this conflict between profit, power and public access to technology (Romans 9:21) is being pioneered by the Rockefeller Foundation, the charity that played a leading role in the Green Revolution[91] and has fifty years experience in supporting public sector agricultural research to benefit the poor and excluded in developing countries. In recent years, it has focused its efforts on increasing production for resource-poor smallholder farmers in Africa. Its Director, Gordon Conway, believes the way forward is through new forms of Public–Private Partnerships focused on specific agreements on IPR in developing countries through Plant Variety Protection systems, thereby making genomic information and technology available to local and publicly-funded plant breeders. This would allow the development of high-quality, locally-adapted seed with the traits required by Third World farmers. One example is the Rockefeller-sponsored African Agricultural Technology Foundation,[92] set up to make IP available for specific projects that apply specific technology to specific problems. It will involve smallholder farmers to identify the problems that are worked on, register new crop varieties in the specific country where the crop will be used and distribute that new crop variety to smallholders. This is not a purely technological fix, but a sustainable solution based on a meld of biotechnology and integrated pest management.[93]

Some Christians believe that GM crops are not needed because enough food is already produced in the world to feed everyone and that it is inequitable dis-

88 Heap *op.cit.* [4].
89 Ye, X. 'Engineering provitamin A (b-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm', *Science* (2000) 287, 303-305.
90 Cantrell, R.P. 'Rice Research: The way forward' in *IRRI Annual Report 2000-2001*, Manila: IRRI (2001).
91 Conway *op.cit.* [4]; Conway and Toenniessen *op.cit.* [83].
92 Terry, E.R. *AATF Newsletter Issue 1, 2002*. Washington DC: AATF, September 2002.
93 Conway *op.cit.* [4] and [41]; and see section 4, below.

tribution, not production per se, that is the root problem. This argument is countered by Derek Burke:

> There's truth in that; for if the world's food supply in 1994 had been evenly distributed, it would have provided an adequate diet of about 2350 calories per day for 6.4 billion people, more than the world population. But distributing it that evenly will not be easy, even if the world's population was not increasing. Of course we should try to do better, but it seems perverse to me to walk away from a potential increase in the world's food supply.[94]

Indeed, some organisations through their desire to campaign 'choose only data and examples that support their goals',[95] although this 'flies in the face of New Testament teaching (2 Corinthians 4:2)'. It is absolutely crucial to separate out the many and complex issues involved in GM crops, to treat each separately and to avoid the temptation either to embrace uncritically or reject absolutely GM crops as a technology. The confusion of separate issues should not lead to outright rejection of the technology. The TRIPS (Trade-related Aspects of Intellectual Property Rights) agreement of the World Trade Organisation (WTO) that ensures that fertilizer is five times as expensive in developing countries as it is in the UK, may be seen as an example of oppression of the poor to be fought against; but it is intellectual laziness to argue that because of such issues we should turn our back on biotechnology as a whole. For example, many of the concerns about GM food expressed currently by Christian Aid on their website in the document *Selling suicide*[96] are shared by many scientists, ethicists and Christians. Other claims in the same document, on soil ecology, the distinction between plant and animal species, regulation and horizontal gene transfer, are scientifically discredited or exaggerated out of all proportion. The result is a much less mature stance than that taken, say, by Oxfam.

The inventor of Golden rice, Ingo Potrykus,[97] has described it as an acid test for groups opposed to GM crops, because he claims it answers all their criticisms. He professes that Golden rice: was not developed by or for industry; complements traditional agronomy; presents a sustainable, cost-free solution, and does not require other resources; avoids the unfortunate negative side effects of the Green Revolution; benefits the poor and disadvantaged, not industry; is given free of charge or restrictions to subsistence farmers; does not create any new dependencies; will be grown without any additional input; creates no advantages for rich landowners; can be resown every year from the saved harvest; does not reduce agricultural biodiversity, affect natural biodiversity, or have any known negative impact on the environment; presents no conceivable risk to consumer health; could not have been developed with traditional meth-

94 Burke *op.cit.* [1].
95 Bruce and Horrocks *op.cit.* [13].
96 Simms, A. *Selling Suicide*, London: Christian Aid (1999).
97 Potrykus, I. 'Golden rice and beyond', *Plant Physiology* (2001) 125, 1157-1161.

ods. If true, this places a great responsibility on those who oppose its introduction, for are we not warned repeatedly against the deliberate ignoring of truth (Proverbs 17:15, Isaiah 6:9, Jeremiah 5:21, Zechariah 7:10-12, Matthew 13:15-16, 43)? But Potrykus[98] avers that the opposition to GM crops has been 'doing everything in its power to prevent Golden rice from reaching subsistence farmers'. This he describes as endurable in rich countries where people live in luxury, but intolerable in poor countries where the technology can make the difference between life and death or between health and severe illness.

To summarise, I have argued that the growing of GM crops does not have consequences that must *of necessity* be outside God's will. In the UK the direct genetic effects of GMHT crops are marginal ecologically, but other traits require assessment on a case-by-case basis. The indirect ecological effects, in common with those of other forms of intensive agriculture, require strict regulation to satisfy our responsibility for wise stewardship. The potential need to increase food production in Third World countries will become ever clearer, but there is considerable work to be done before the use of GM technology conforms to goals for feeding the hungry. Drastic changes are needed to the delivery of GM technology to ensure equitability and sustainability. Hence, we must seize the opportunity to 'regulate this coming change with the best technical expertise and an impartial sense of social justice'.[99]

4. The Future

One of the most urgent questions for the future of biotechnology in the UK is a hypothetical one raised regularly by the proponents of GM crops. 'Given that ACRE have already determined that there is no threat to human health or the environment,' they ask, 'if the FSE should then show that there is a broadly neutral effect on farmland wildlife of GMHT management compared to conventional, why shouldn't the Government proceed immediately to commercialisation?' I believe this question is based on the false premise that views the status quo as acceptable. Whatever is or is not shown by the FSE, we already have *plenty* of evidence that the increased intensity of farming since the Second World War is the most likely cause of the decline of several important farmland species of birds, butterflies and other taxa,[100] often through indirect effects mediated through loss of habitat and decline in weed and invertebrate populations. Unless it were clear that the application of GMHT management would lead inevitably to a reversal of this decline, to recommend its commercialisation in an unrestricted fashion would, in my view, be to relinquish the responsibility of stewardship given us by God in Genesis 2. Indeed, those who work in agro-ecology are in a position to give a warning about this, and have a duty to

98 Potrykus *op.cit.* [97].
99 Burke *op.cit.* [1].
100 Krebs, Wilson etc. *op.cit.* [30]; Robinson and Sutherland *op.cit.* [31]; Chamberlain, Fuller etc. *op.cit.* [82].

do so (Ezekiel 33:1-6; Luke 12:48).

It is indeed unfortunate for the biotechnology industry that their products have reached the market place at the same time as three events have occurred that have marked a watershed in UK agriculture. Firstly, there is an economic crisis in the agricultural industry; secondly, there is consensus within the UK regarding the pressing need for Common Agricultural Policy (CAP) reform in Europe; and thirdly, there is considerable public pressure on the UK Government to take steps to ameliorate deleterious effects of agriculture on the environment. The convergence of these events gives a particular context to the decision-making process over GM that would not have been present, say, a decade ago; it has already led to a major review of policy as outlined in the Curry Report.[101] Proponents of biotechnology argue that this is not a fair way to judge the acceptability of products, that in focusing so strongly on the effects on biodiversity the regulatory authorities are effectively imposing conditions on agricultural products that have never been required previously. Their argument is that there can be little wrong in principle with the replacement, say, of conventional oilseed rape by herbicide-resistant rape, and that whether the herbicide resistance is induced into the plant by conventional plant breeding (which has indeed long been achieved) or genetic modification is irrelevant. This is a valid point. But were not Jacob, Jonah, Isaiah, Peter, the brother of the Prodigal Son, the tenth leper, the good Samaritan all asked to do more than what could reasonably be expected? Did not Jesus call individuals to try to achieve more than they thought they were capable of, 'to go the extra mile'?

Whether we like it or not, and whether we agree or not, public attitudes towards UK agriculture have changed radically over the last five years. The biotechnology industry seems not to grasp that the relationship in the UK between farmland, semi-natural habitat and wilderness areas is fundamentally different from that in the USA. Unlike those in the USA, our farms and their environment coexist in an inextricably linked and patchy mosaic of different habitats.[102] As Hails[103] puts it, we effectively live inside our national parks. Even if the public were convinced that it was relatively harmless, I cannot see how they would accept the commercialisation of GMHT crops unless it were shown to them that there could be positive associated *improvements* in farmland wildlife. The maintenance of the old status quo of a steady decline in biodiversity is no longer acceptable, ethically or politically.

However, I do *not* believe this puts an insurmountable block on the introduction of GM technology in the UK. Fortunately, we know enough to impose particular mandatory restrictions on the way GM crops are grown so as to

101 Policy Commission on the Future of Farming and Food. *Farming and food: a sustainable future*. London: The Cabinet Office (2002).
102 Perry (2001) *op.cit.* [2].
103 Hails, R.S. 'Assessing the risks associated with new agricultural practices'. *Nature* (2002) 418, 685-688.

ensure a positive *benefit* to biodiversity, at the expense of a relatively small amount of yield. Specifically, pioneering work by colleagues at Brooms Barn[104] has indicated how delays in spraying weeds in GMHT beet crops may provide food resources and habitat structure during a critical part of the year for insects and nesting birds, and how this may be combined with innovative band-spraying techniques to improve abundance further. Additionally, GMHT crops could operate in a reduced-tillage system to protect earthworms and other soil invertebrates[105], and in agreed rotations favourable to wildlife. The compulsory spring-sowing, rather than winter-sowing, of some types of GM crops might do much to provide overwintering food and habitat for birds and beneficial invertebrates.[106] Such measures could be combined with obligatory imposition of Integrated Pest Management[107] techniques to reduce pesticide applications, including the use of: biocontrol,[108] the encouragement of the natural enemies of pests; improved forecasting and monitoring of pests; encouragment of pollinators; non-systemic insecticides; alternative pest control using semiochemicals; anti-pest-resistance strategies; conservation headlands as developed by the Game Conservancy;[109] beetle banks as developed by the University of Southampton;[110] and managed set-aside.[111] The success of these techniques is now well documented.[112] Additional enforced use of precision agriculture[113] on GM crops could help target and optimise inputs of fertilizer. All this could be backed up by studies to ensure GM crops do not have unforeseen, indirect effects on non-targets.[114] Finally, we have the knowledge to implement these approaches, particularly through wise targeting at field margins.[115]

104 Dewar, Haylock etc. *op.cit.* [32].
105 Hails *op.cit.* [103].
106 Hald, A.B. 'The impact of changing the season in which cereals are sown on the diversity of the weed flora in rotational fields in Denmark', *Journal of Applied Ecology* (1999) 36, 24-32.
107 Cate, J.R. and Hinkle, M.K. *Integrated pest management: the path of a paradigm. Special Report*. Washington DC: National Audubon Society (1993).
108 van Driesche, R.G. and Bellows Jr., T.S. *Biological Control*, New York: Chapman & Hall (1996).
109 Sotherton, N. 'Conservation headlands: a practical combination of intensive cereal farming and conservation' in Firbank, L. (ed.) *The Ecology of Temperate Cereal Fields*, Oxford: Blackwell Scientific Press (1991) pp. 373-397.
110 Thomas, M.B. 'Creation of 'island' habitats in farmland to manipulate popuations of beneficial arthropods: predator densities and emigration', *Journal of Applied Ecology* (1991) 28, 906-917.
111 Firbank, L.G., Arnold, H.R., Eversham, B.C., Mountford, J.O., Radford, G.L., Telfer, M.G., *et al*. *Managing set-aside land for wildlife*. London: HMSO (1993).
112 MAFF *Reducing Agrochemical Use on the Arable Farm*, London: MAFF (1998); Stoate, C. and Leake, A. *Where the birds sing*, Loddingon: Game Conservancy Trust & Allerton Research and Educational Trust (2002); Association of Applied Biologists. 'Farming systems for the new Millennium', *Aspects of Applied Biology* (2000), 62.
113 Stafford, J.V. 'Precision Agriculture '99' in *Proceedings of 2nd European Conference on Precision Agriculture, 11-15 July 1999, Odense Congress Centre, Denmark*, London: Society of Chemical Industry & Sheffield: Sheffield Academic Press (1999).
114 Poppy *op.cit.* [35].
115 Marshall, E.J.P. *Guidelines for the siting, establishment and management of arable field margins, beetle banks, cereal conservation headlands and wildlife seed mixtures*, Long Ashton, Bristol: IACR-Long Ashton and MAFF (1998).

This approach could ensure a balance between productivity and conservation; it represents a way for intensive agriculture to redeem itself in the eyes of the public. Further, it would surely receive overwhelming support from those scientists best in a position to judge its worth and to suggest details for its implementation:[116] those agro-ecologists who have laboured for many years in a relatively unfashionable area of science and whose best ideas have often been shelved because of lack of political will. They could use their creative skills to demonstrate what could be achieved for farmland wildlife. Hopefully, the system devised could then act as a paradigm for future compulsory use in *conventional* agriculture, as envisioned in the Curry Report[117] which speaks of the farmer as *steward* of the countryside. This is a rational, non-dogmatic, evidence-based approach. It is in line with the outcomes of consumer pressure on supermarkets that have led to initiatives such as Tesco's 'Nature's choice' scheme.[118] It should promote the involvement of NGOs such as LEAF (Linking Environment and Farming), the Game Conservancy, FWAG (Farming and Wildlife Advisory Group) and the RSPB (Royal Society for the Protection of Birds), that have a good track record of encouraging the wise stewardship of arable land. It represents a real and imaginative third way for farming, integrating agronomy, biotechnology and ecology.

There are other current challenges with regard to the possible UK commercialisation of GM crops. Two are consumer choice and the coexistence of GM crops with conventional and organic forms of agriculture,[119] for which the AEBC has a subgroup. Another is the liability for genetic contamination of one crop by another. Here, Christians have questioned:

> the rights of different groups to impose their own agendas on society at large. How far is society obliged to bow to one group who claims that the growing of GM crops represents a commercial threat, primarily because of the way they have chosen to define their own business? On the other hand, how far is another group justified in claiming it as their commercial right to have the opportunity to grow GM crops? Neither can presume an exclusive claim.[120]

Christians who are also senior scientists have contributed greatly to the UK debate on GM crops over recent years. The general approach taken by workers such as Berry, Bryant, Burke, Heap, Polkinghorne, Reiss and others has been one of distinction. It has been positive, engaged with the public, has mixed sci-

116 Perry (2001) *op.cit.* [2].
117 Policy Commission on the Future of Farming and Food *op.cit.* [101].
118 Select Committee on Agriculture. *Second Report, Appendix 27 to the Minutes of Evidence*. London: HMSO (2001), and see http://www.parliament.the-stationeryoffice.co.uk/pa/cm200001/cmselect/cmagric/149/14903.htm).
119 Perry, J.N. 'Minutes & transcripts of evidence-taking session' in *Report of Fourteenth Agriculture and Environment Biotechnology Commission Meeting at the Royal Society of Edinburgh*, London: AEBC (2002); 'Sensitive dependencies and separation distances for GMHT crops', *Proceedings of the Royal Society, Biological Sciences* (2002) 269, 1176-1179.
120 Bruce and Horrocks *op.cit.* [13].

entific rationality with prudence, is unsullied by attachment to big business, has due humility and recognises fallibility. They have generally argued for a retention of the right to creative action and the need for wise judgment. This approach is in consensus with the Government, the AEBC, and the Royal Society, who all agree that (i) public opinion must be taken into account in any decision over commercialisation but that (ii) risk must continue to be evaluated in a measurable way through the gathering of empirical data.

The Christian has much to offer, in an area in which there are many difficult and conflicting issues to balance: personal integrity, an objective set of values, a readiness to listen to others, and a willingness to pray for guidance from the Spirit, particularly regarding the uses to which the technology is put. I have argued elsewhere that it is a pity that this distinctive collective contribution was not recognised explicitly in the AEBC report *Crops on Trial*,[121] which stressed the sociological at the expense of the bioethical issues and ignored the considerable *existing* published body of evidence of that ethical debate. Unfortunately, a good opportunity was thereby squandered of communicating to the public how seriously bioethics is taken by many of those scientists who are themselves active in the field of biotechnology. The challenges for Christians will remain for many years, both at a corporate and individual level. Not least among these is the requirement to pray for those with whom we disagree, even when they trash our experiments.

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121 AEBC *op.cit.* [29].