SESSION 1A

OPENING CEREMONY AND KEYNOTE LECTURES

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Papers:	Keynote Presentations 1A-1 to 1A-4

Increased crop productivity from renewable inputs – a scientific challenge for the 21st century

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ABSTRACT

Over the last 40 years, the increase and stability of crop production in industrialised parts of the world has been a dramatic example of the successful application of science for human well-being. However, early in the 21st century there are new challenges that science must address. The demand for increased crop productivity over the next 50 years will be driven by population growth and trends towards urbanisation in developing regions of the world. This is incompatible with the relatively costly, fossil-carbon dependent inputs (fuel, nitrogen fertilisers and application of synthetic biocides) that have provided the basis for much of the increased crop productivity on which the developed world is now dependent. At the same time, the annual loss of productive agricultural land and pressure on water resources throughout the world are causes for concern. There are strong economic and environmental arguments of relevance to both the industrialised and developing world that point to the need for new technologies that have the potential both to increase crop productivity and substitute for the non-renewable inputs that in the long-term are not sustainable. In this context, the application of burgeoning knowledge derived from "omics" technologies will be of great benefit when applied to studies of organisms detrimental and beneficial to agriculture. Nevertheless, the demand for increased productivity will not be delivered solely through crop genetic improvement, vital though this will be. New knowledge is providing the potential to reduce yield loss due to pests, pathogens and weeds through the development of sustainable crop technologies based on the renewable exploitation of beneficial whole organisms and molecules that mediate interactions between them in the agricultural ecosystem. There is a strong case for targeting increased scientific effort towards greater mechanistic understanding of the interactions that take place between organisms in agricultural ecosystems and the development of technologies that emphasise the exploitation of renewable inputs.

INTRODUCTION

Land management in the industrial and developing world: reconciling scientific priorities

Just a few generations ago there was almost no part of the globe that was free from deprivation resulting from unpredictable food supply. Thanks to the application of science, we are, in Europe at least, confident of a predictable supply of sufficient, good quality, affordable food. However, at the start of the 21st century, northern Europe is experiencing an accelerated change of priorities for the use and management of land that started about two decades ago. Today's context for land management in northern Europe relegates the importance of agricultural production as a consequence of: the inevitable expansion of the European Union, the globalisation of world trade, the expectations of an increasingly prosperous population, the strengthening "green agenda" and the socio-economic value accorded to land for purposes other than agricultural use. Forward projections suggest that the demand for food by the population of Europe could decrease over the next 50 years. Nevertheless, those of us who reside in Europe should not forget that over 840 million people worldwide are at present undernourished and the population of the globe is set to rise from 6 billion to 9 billion by 2050. In the next 50 years, the world must produce at least 75% more food than it does at present to sustain the projected increase in population (Evans, 1998).

In the context of future investment in science, how can the changes that affect priorities for land management in Europe be reconciled with the requirements of the world's disadvantaged populations for land and food? Is there any common ground between the apparently disparate requirements from science of primary producers in the developed and developing world? The answer to these questions lies in the acquisition and application of scientific knowledge that will enable the delivery of truly sustainable production systems predominantly based on the exploitation of renewable natural resources. Simply put, there can be only one global scientific priority in the context of land management in the 21st century. A uniformly applicable goal for scientific endeavour must be the acquisition of new knowledge, translated into new technology, which will enable greater productivity per area of land in parallel with reductions in the consumption of non-renewable resources.

This paper explores some of the options with a primary focus on how reduction of crop yield loss due to herbivory and pathogenic infections might be achieved through a greater mechanistic understanding of the interactions that take place between organisms in agricultural ecosystems

Land as a non-renewable resource

It is estimated that each year 9m hectares of land are lost to agricultural production and over half of this is due to urbanisation (Evans, 1998). The value that is placed on land for purposes other than food production, whether in Europe or elsewhere, means that there is no sound argument for cultivating more land than is absolutely necessary to achieve the required output of biomass. This is regardless of whether the reason is to conserve natural habitat or to develop sought after amenities. Both pressures exist in the industrialised and developing world. In this context, it should not be taken for granted that land itself can be considered a wholly renewable resource. To avoid the requirement for more land to be devoted to agricultural production there is a need for an intensification of science-based management as a mean of achieving reductions in non-renewable inputs.

The paradigm of "industrial agriculture": requirements for substitute technologies

The classical Broadbalk winter wheat experiment at Rothamsted has generated data since 1843 and mirrors the paradigm of crop production in the industrialised world. For about 100 years, using a sequence of different varieties, yields of continuous wheat grown on plots receiving no inputs were between 1 and 1.5 tonnes per hectare. Over this same period it was clearly demonstrated that yields could be predictably doubled with inputs of farmyard manure or mineral fertilisers. Both sources of plant nutrients were equally good at sustaining yields for four generations. In the 1940s, a good yield was 3 tonnes of wheat per hectare but from the 1960s on, yields increased three-fold with the introduction of semi-dwarf varieties, the deployment of genetic disease resistance, and the judicious use of herbicides, fungicides and insecticides (Rasmussen, *et al.*, 1998). As a consequence of these advances, crops yielding 10 tonne per hectare can be achieved regularly. However, these remarkable levels of output have been attained for barely two generations and it is evident that some of the inputs that drive the current level of output are not genuinely sustainable.

High-input agriculture in the industrialised world is heavily dependent on fossil carbon in the form of fuel (for almost all agronomic practices) and for agrochemical manufacture and delivery. Such inputs contribute to global climate change as well as being finite in supply. Agricultural practice also contributes to nutrient enrichment of aquatic and terrestrial non-cultivated habitats with adverse effects on biodiversity. A less frequently considered impact on the sustainability of agriculture in the industrialised world results from the force of evolutionary change within populations of organisms detrimental to crop productivity. Hence, pathogens evolve to overcome genes for resistance while weeds, pathogenic fungi and insects evolve resistance to the agrochemicals used to reduce the size of their populations.

Despite what some at the extreme "green fringe" might argue, there is no case for the wholesale abandonment of valuable technologies that have had such a beneficial impact on the well-being of a substantial proportion of humanity. However, with a view to future generations and particularly those in the developing world, there is an urgent need for new, substitute technologies, founded on sound science, which will, in time, replace dependency on non-renewable resource and unsustainable practices. This paper is about the investment in areas of science that show promise in delivering these substitute technologies.

Sustainable land management and the promise of integrative biosciences

Agricultural ecosystems represent complex interactions between large numbers of different organisms both beneficial and detrimental to the production of the quality and quantity of biomass sought by dependent human populations. Understanding these interactions at the level of whole organism biology is of crucial importance. However, to understand the biology of individual whole organisms requires an integration of knowledge from the level of cells and molecules drawing on chemistry, genetics, biochemistry and molecular biology. Similarly, while different organisms interact with one another as individuals, the outcome of importance is the consequence of the multitude of interactions between many individuals; in other words, interactions at the level of populations. The scientific and technological progress required to achieve truly sustainable systems of land management is therefore underpinned by the concept of integrative bioscience and a vision of the more predictive understanding of complex systems than is possible at present.

At the start of the 21st century, there is a burgeoning of knowledge about how biological systems work. This explosion of information is being catalysed by access to whole genome DNA sequence and a new productive synergy between the biological, physical and mathematical sciences. There is a real cause for optimism that new products and practices will emerge from this knowledge-based revolution. In the context of integrative bioscience of relevance to sustainable agricultural production, the scientific community now has access to the whole genomic sequence of several relevant organisms: rice and arabidopsis, two insect species, a nematode worm, some filamentous fungi and numerous bacteria. The promise of integrative bioscience is that it will be possible to develop verifiable predictions, often formalised in mathematical models, about how a complex ecosystem behaves and how best it can be managed for benefit. Knowledge derived from integrative bioscience can be expected to spawn technologies that will substitute for those that at present cannot be abandoned without severe economic penalties, but which are acknowledged as being unsustainable in the long-term.

INVESTING IN A SUSTAINABLE FUTURE: ANALYSING THE OPTIONS

It has been estimated that up to 40% of potential global crop yield is lost to herbivores (vertebrate and invertebrate), infectious pathogens and competition from weeds. This level of loss is despite a reservoir of scientific knowledge accumulated over 150 years and the application of some spectacularly successful chemical technology over the last 50 years. Minimisation of this loss must be a high priority for the future given the increasing pressure on land and other natural resources, including clean water and air. The rest of this paper will concentrate on the prospect of sustainable new technologies to minimise loss due to crop infectious disease and invertebrate herbivores.

There are broadly three approaches to the task of reducing crop losses due to pests and pathogens:

- application of chemicals to the crop or crop environment;
- exploitation or manipulation of plant defence mechanisms;
- harnessing natural ecological constraints on the size of pest and pathogen populations.

Analysis of the key characteristics that might be sought from sustainable substitute technologies for each of these approaches is potentially instructive and is attempted below.

Application of chemicals to the crop or crop environment

In the context of sustainability, the status of existing chemical crop protection practices can be summarised as follows:

- The synthesis and application of chemicals to crops and the crop environment is at present substantially dependent on the exploitation of fossil carbon for either energy (as fuel) or precursors for synthesis.
- A successful crop protective chemical will generally be efficacious against a diversity of target organisms on a range of crops in a wide variety of environments.
- A loss of efficacy can be anticipated for any highly active toxophore with a specific mode of action due to the evolution of insensitivity (resistance) among target organisms.

Consequently, any successful substitute technology with an improved sustainability profile should:

- mirror the broad-spectrum applicability of today's technology;
- exploit the renewable biosynthetic potential of plants or microbes;
- not involve methods of application that require repeated treatments of large areas with substantial quantities of material;

- not impose intense selection on populations of target organisms that will compromise efficacy.

Exploitation or manipulation of plant defence

Since the turn of the 20th century, there has been a sustained effort to develop crops that are more resistant to pests and diseases. There have been many notable successes and the exploitation of genetics either through the processes of conventional plant breeding or, more recently, by application of transgenic technology can be considered as an exemplar of technology based on renewable resources. However, even the very best resistance gene will only exert its effects against a limited number of targets on at most a few crops. This limitation is compounded by the fact that an enormous range of different genotypes is required for every crop species because of the diverse environments in which crops are cultivated as well as the wide range of different uses and quality attributes demanded. In common with crop protective chemicals, loss of resistance gene efficacy results from selection for virulence imposed on populations of target organisms.

In the context of today's technology therefore, effective chemistry will always have far greater impact than effective genetics. Hence, any successful substitute genetics-based technology with an improved sustainability profile should:

- avoid the need for transformation or introgression of rare alleles or transgenes into a diverse range of different adapted crop genotypes;
- not impose intense selection on populations of target organisms that will negate efficacy.

Despite important advances in genetic technologies that will make plant breeding more efficient, genetic improvement alone does not represent a panacea for removing the constraints on production imposed by pests and diseases.

Harnessing ecological constraints

All organisms have their ecological competitors, antagonists, predators and parasites. Invertebrate herbivores and pathogens that derive their nutrition from crops are no exception. Exploiting the "natural" ecological processes that reduce the population size and dissemination of crop pests and pathogens has had some success and particularly when the abiotic environment is sufficiently constant to be able to predict the dynamics of the interactions between the target organism and the chosen agent of biocontrol. While loss of efficacy due to the evolution of resistance to biocontrol agents has not often been recorded, there is no reason in principle why this should not occur. In common with the deployment of genetic defences, biocontrol technology exploits a renewable resource but, similarly, the efficacy of any particular agent may be highly restricted to a particular target or crop. Hence, any successful substitute, ecologically-based technology with an improved sustainability profile should:

- have a broad-spectrum of applicability;
- be self-sustaining;
- not impose selection on populations of target organisms that will negate efficacy.

The profile of a sustainable technology

It is evident that an effective synthetic chemical (derived from and applied using non-renewable fossil carbon) can remove constraints on the production of many different crops in many geographical regions. However, evolutionary change and economic considerations, in addition to the dependency on a non-renewable resource, makes this technology unsustainable. At the same time, the most effective resistance gene or biocontrol agent, which each represent the exploitation of renewable resources, are also subject to loss of efficacy due to evolutionary change and yet remove rather a limited number of constraints on perhaps a single crop in a single geographical region.

Given this analysis, what does the profile of a truly sustainable technology look like and how might it be possible to work towards its provision? The conclusion is that such a technology should:

- be based predominantly on exploitation of one or more renewable resources;
- not be subject to loss of efficacy due to evolutionary change;
- have a broad-spectrum of applicability;
- have a cost profile commensurate with local economic conditions and crop value.

This analysis poses the interesting and challenging question: where is there any glimmer of prospect from current scientific knowledge that would suggest that the development of such a technology would be possible? The answer to this question resides in two well-established observations summarised below.

Prospects for meeting the challenge of providing sustainable technology

The first observation is that plants do not provide an appropriate environment for the reproduction of all but a very restricted sub-set of the potential herbivores and infectious agents with which they could possibly come into contact. In other words, it is very exceptional for a potential pathogen or herbivore to be able to exploit any particular plant species as a source of nutrients and thereby sustain its development. This specificity of access for pathogens and herbivores to only a very restricted proportion of the potential living plant biomass in their environment (plant pathologists refer to this phenomenon as non-host resistance) is the consequence of eons of co-evolution and is not subject to the rapid evolutionary changes alluded to above that negate the efficacy of today's crop protection technologies. A theoretical sustainable technology would harness this "specificity of access for pathogens and herbivores" would "have a broad-spectrum of applicability" and "be based exclusively on exploitation of one or more renewable resources".

The second observation is that there is communication between plants and other organisms in their immediate environment through the two-way perception and response to chemical signals. For example, plants receive chemical signals from potential pathogens or herbivores and use these signals to mediate defences that only fail in exceptional cases. It is these exceptional cases of failure that equate to the rare occasions when it is possible for a potential pathogen or herbivore to derive nutrition from a particular plant (see above). Conversely, a particular plant-derived chemical signal or cue may be essential for successful pathogenesis or herbivory with absence of the signal or an inability to perceive it resulting in a plant being inaccessible. This chemical communication is based on the products of biosynthesis and involves molecules that exert their biological effects at low concentration. The ability to harness plant sensing and signalling systems could, in theory, deliver the four characteristics, identified above, of a truly sustainable technology.

In summary, is there a prospect for discovery and exploitation of molecules, derived from a renewable source, that can be delivered to plants and provoke them to be as inaccessible to the rare pathogens and herbivores that exceptionally breach their normally effective defences as they are to the majority that do not? Is the production and administration of naturally derived chemicals that will activate the responses that make most plants resistant to most pathogens and herbivores an achievable reality?

EXPLOITING SIGNALLING SYSTEMS: A REALITY CHECK

Cellular signalling: recognition and response

On the basis of available evidence, a reasonable working hypothesis is that all plant cells have the capacity to recognise non-self and actively to elaborate a defence response. It is also a reasonable assumption that the defence response of all plants is essentially similar except for phylogenetic variation in associated downstream secondary metabolism (Somssich *et al.*, 1998). Specificity is most likely to reside in the process of recognition such that successful pathogenesis or herbivory results when an invader fails to deliver a signal that the plant's surveillance apparatus can detect or, alternatively, when the cellular machinery required for the surveillance apparatus to function is rendered ineffective.

Microbial and viral pathogens produce a diversity of molecules (so-called elicitors) that are capable of bringing about alterations in the metabolism of plant cells putatively involved in defence. Some of these molecules (primarily peptides) are highly specific in their interactions with plants of a single species carrying a specific putative receptor encoded by a particular gene. This is the conceptual basis of the well-described gene-for-gene relationship as well as for the occurrence of micro-evolutionary change over short time periods resulting from selection acting on within-taxa allelic variation at loci involved in the process of recognition (Crute, *et al.*, 1997).

Many hundreds of plant genes responsible for genotype-specific recognition of particular pathogens and invertebrates (so-called *R* genes) have been identified over the last 100 years and, over the last 10 years, some dozens of these *R* genes have been isolated and sequenced with details of their evolutionary origins and the way they are organised within plant genomes emerging from associated studies (Meyers, *et al.*, 1999). Several different classes of *R* genes exist in plants and access to whole genome sequences now indicates the existence of about 150 "resistance gene analogues" (RGAs) in one genotype of arabidopsis and about 1700 in rice (for which function has been attributed to relatively few). R genes with structural homology are now known to mediate resistance to agents as diverse as: fungi, oomycetes, bacteria, viruses, nematodes, aphids and whiteflies.

The protein products of R genes function as components of a signal-transduction system. A putative receptor recognises molecules indicative of the presence of a potentially damaging alien organism (i.e. "non-self") and activates the plant's generic defence responses. The receptor and signalling system has numerous components now being dissected by genetic and biochemical analyses with R genes representing one such component. Recognition specificity may be contributed primarily, but not exclusively, by a leucine-rich repeat domain (LRR) common to the proteins encoded by different classes of R gene. This domain comprises a variable number of repeats of the motif xxLxLxx (where L is a conserved aliphatic residue, leucine or isoleucine) putatively providing an array of solvent-exposed ligand-binding surfaces. For several RGA gene families, regions of the LRR have been shown to be under diversifying selection as indicated by a ratio of greater than one for the synonymous to non-synonymous substitutions of the nucleotides encoding residues in the region (excluding the conserved aliphatic residues) (Michelmore & Meyers, 1998). On the basis of phenotypic specificity, there is no evidence that any one R allele has affinity for more than one ligand. However, there is no intrinsic reason why this would not be the case and the degree of ligand affinity is likely to be another attribute of RGAs on which selection will act.

There is potential for enormous sequence variation to be manifest by RGAs represented within a single plant genome, within the gene pool of a particular plant population and among the diversity of genotypes represented by any particular plant species. Within and between individual plants the way in which the molecular machinery for signal recognition and transduction is assembled is likely to be subject to combinatorial variation. It is likely that the exposure of such variation to selection will have resulted in the ability for individual plants to recognize and respond effectively to molecules that represent the invariant molecular signature of potential pathogens and herbivores. It is envisaged therefore that there are taxon-specific molecules that are invariant and biologically essential to particular groups of pathogen or herbivore but which also represent the means whereby all but a small sub-set of plants (which act as receptive hosts) are recognised as potentially damaging invaders. Genotype-specific interactions mediated by gene-for-gene recognition may therefore represent just the "tip of an iceberg" in inter-organismal associations.

The identification of a RGA receptor in arabidopsis involved in response to a conserved domain of bacterial flagellin (Gómez-Gómez & Boller, 2000) provides evidence for the concept outlined above, as does the circumstantial evidence for a surface receptor on parsley cells that is seemingly involved in perception of a pathogen-associated molecular pattern (PAMP) common to all members of the genus *Phytophthora* and the subsequent elicitation of defence responses (Brunner, *et al.*, 2002).

In tomato, a gene called *Fen* is a paralogue of a gene called *Pto* that confers resistance to the bacterial speck disease caused by *Pseudomonas syringae* pv. *tomato*. Tomato genotypes carrying *Fen* display a phytotoxic necrotic flecking reaction to the synthetic insecticide fenthion (Loh & Martin, 1995). Other examples of genotype-specific necrotic responses to particular synthetic chemicals have also been reported. The implication is that plant receptor systems have evolved to detect molecules that originate from potentially damaging organisms with which they may come into contact but that these receptors are sufficiently promiscuous to detect novel synthetic molecules and initiate cellular defence responses.

Beyond the initial perception of the signal, chemicals of natural or synthetic origin that provoke plants to activate their defences are known. The consequence of exogenous application of such chemicals can be elevated resistance to subsequent challenge from a diversity of potential pathogens or herbivores. Examples include two compounds: salicylic acid (SA) and jasmonic acid (JA), that occur naturally in plants and signal the occurrence of pest or pathogen attack provoking subsequent cellular defence responses remote from the site of initial stimulus. Two synthetic analogues: 2,6-dichlor-isonicotinic acid (DCINA) and benzol (1,2,3) thiadiazole-7-carbothioic acid S-methyl ester (BTH) have been shown to mimic the effects of SA with the latter being formulated as a commercial disease control product (Bion) (Lucas, 1999). Exogenous application to plants of the (non-protein) amino-acid, β-amino butyric acid (BABA), also exerts similar non-specific effects but seemingly not mediated through SA or JA (Cohen, 2002). These observations provide some additional support to the notion that the integration of biological and chemical technologies may facilitate the manipulation of cellular defence responses in crops.

In summary, there are glimmers of evidence that suggest the possibility that the same types of receptor systems that are now known to be involved in genotype-specific recognition by plants of pathogens and herbivores may also be involved in the generic protective detection of "non-self", including the myriad of organisms to which the particular plant is not a receptive host. This opens the prospect of being able to deliver to any individual of a particular plant taxon (species, genus or family) a signal molecule that is recognised by an existing receptor displaying no functional polymorphism within the taxon and capable of generating an effective protective response to an organism that would otherwise not provoke such a response.

Molecules mediating insect behaviour

It has been discovered that parasitic wasps locate their aphid hosts by using the same chemical signal as the male aphid uses to find the female. The chemical structure of these aphid sex pheromones is known. One such molecule, a specific isomer of nepetolactone can be produced from a plant source, *Nepeta* spp. (cat mint), providing the opportunity for a new crop protection technology based on a sustainable natural product (Birkett & Pickett, 2003)

It has also been shown that when plants are attacked by herbivorous insects (and by pathogens) they are provoked to emit a different profile of volatile molecules to that characteristic of the un-attacked plant. This altered profile of volatiles is an indicator that the plant is "under-attack" and such information could be conceived as having benefit to both other plants in the vicinity (which could mount their own defences ahead of subsequent attack) and organisms that might benefit from locating either the invader or the damaged plant itself. In this context, components of altered volatile profiles from plants have been shown to attract parasitoids which assist in the defence of the plant by depleting the numbers of invading aphids. Evidence that other plants in the vicinity can detect alterations in the volatile emissions from neighbouring plants has also been obtained and such plants become less receptive to aphid attack (Pickett & Poppy, 2001). It has recently been discovered that a lipid-derived molecule, cis-jasmone, is involved in this signalling phenomenon and using array-based technology certain cis-jasmone responsive genes are in the process of being characterised.

In summary, there is accumulating evidence for molecular communication between individual plants within populations and also that plants can mediate the behaviour of beneficial and detrimental organisms with which they are associated. The concept of triggering plants, possibly through the appropriate construction of mixed species or genotype plantings, to emit the necessary signals to optimise their defence against both herbivores and pathogens does not appear too far fetched.

Delivery systems

The thesis advanced above is that is will be possible to reduce the constraints on crop production imposed by pathogenesis and herbivory through the identification and delivery to plants of particular molecules for which there are specific receptors whose stimulation results in an elevation of resistance or attracts the attention of "natural enemies". This concept integrates much of the knowledge and experiences gained over many decades with the three conventional approaches to crop protection summarised above. The concept also fulfils most of the attributes for a substitute sustainable technology. However, it is not immediately obvious how this concept will be delivered if it is to: "avoid the need for transformation or introgression of rare alleles or transgenes" and also "not involve methods of application that require repeated treatments of large areas with substantial quantities of material" (see above). How will it be possible to deliver this technology to existing and future genotypes of a range of crop species in a range of environments without resorting to the production of transgenic crops and, or, conventional approaches to chemical application and continued dependency on fossil fuel inputs?

A possible answer to this challenge comes from increasing knowledge of the interaction between plants and associated bacteria that live either on their external surfaces or within their tissues. Plants are colonised by a diversity of bacteria that originate from seed, vegetative propagules or soil. Some of these organisms colonise the surfaces of roots or aerial parts while others are endophytic. There is increasing evidence that there is a multiplicity of chemical signalling between plants and these plant-associated microbes. Manifestations of this are the well-described molecular interactions between *Rhizobium* species and their legume hosts and the less well-characterised but relevant observation that bacteria in the rhizosphere are capable of influencing the resistance of plants to pathogenesis of their aerial parts (Pieterse, *et al.*, 2002). Knowledge is also increasing of the mechanisms whereby bacteria deliver signal molecules to plant cells or into their immediate environment.

Seed or some relatively small vegetative propagule provides the basis for the establishment of most crops (with the exception of long lived, perennial, woody species). Hence, an effective system to deliver a "signalling-based" technology for crop protection would require:

- identification of the signalling-molecule of pathogen or herbivore origin;
- an ability to "engineer" signalling molecule production in a bacterium capable of reliable colonisation from an inoculum applied to the planting propagule;
- transfer of the signalling-molecule to the plant in an ecologically relevant context to effect elevated defence.

Although not strictly analogous, the natural protection from large herbivores afforded to plants by colonisation with toxogenic fungal endophytes provides an actual example which might indicate the scenario outlined above is not altogether fanciful.

CONCLUDING REMARKS: FUTURE RESEARCH PRIORITIES

This paper has provided an analysis of the need for and characteristics of new sustainable crop protection technologies. Such new approaches are required for application in production systems within developed and developing country agriculture if escape from unaffordable, polluting technologies reliant on non-renewable resources is to be achieved. However, while some elements of the necessary building-blocks for provision of these new approaches are in place there is a significant lack of fundamental knowledge on which to found rapid progress.

Intensification of research in several areas is required since this will have value regardless of whether the precise format for delivery of application is as envisioned in this paper. All these areas require a multidisciplinary approach and will doubtless benefit markedly from the application of the raft of new post-genomic analytical methodologies. The logical conclusion from the foregoing discussion is that emphasis needs to be placed on:

- identification and elucidation of synthetic pathways for taxon-invariant molecules essential for pathogenesis and herbivory which provide the basis for plant perception of non-self;
- elucidation of cellular recognition and response pathways in plants with an emphasis on the identification of taxon-invariant receptor molecules that provide the basis for perception of non-self and detection of generic signalling molecules;
- the molecular ecology of interactions between prokaryotes and plants with particular reference to attributes conferring colonisation capability and mechanisms involved in exchange of signals.

It is evident that reliance on today's technologies does not provide a sustainable solution to the imperative of increasing global crop output per hectare in the face of climate change, population growth and non-agricultural demand for land. The challenge to science is to provide the knowledge on which to build alternative, substitute technologies that will sustain thriving human populations well into this century and beyond. The research priorities enunciated above not only represent exciting science from which new and unforeseen opportunities will emerge but they also represent a response to a coherent vision of where the future may be.

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Impact of genomics on the Food Chain

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ABSTRACT

In the 50 years since the discovery of DNA structure, the acceleration in genetic data production and its conversion to useful information has driven completely new approaches to the study of living systems. A new language of science has developed, so that those of us who are not practicing geneticists have a hard time keeping up.

The initial impact has been in agriculture, producing novel crops and animals with the primary benefit of increased yield of food commodities. Not surprisingly, the speed and novelty of these developments has not met with universal approval, and concerns for safety and environmental impact are strong, particularly in Europe. Nonetheless, the uptake of GM technologies are worldwide, and within a few years there will be a minority of people who have not eaten some foodstuffs containing GM material or produced with the assistance of enzymes or process aids in which the technology is involved. On a worldwide basis, there is every reason to believe that benefits other than yield improvements will be significant. Quality traits relevant to post harvest processing and storage have already been demonstrated, and those with a direct benefit to human health will be irresistible.

The modern Food Chain is a complex set of industries, and the impact of genomics is not just on a simple flow of foodstuffs from "field to fork". Neither is this impact necessarily limited to GM food. Understanding the genetics of stress driven gene expression will clarify the targeting of breeding and the empirically derived knowledge of agronomy. The food ingredient producer can look forward to a whole range of sophisticated molecular species whose production, isolation and performance is better understood. Manufacturers anticipate that raw materials will be specified for processability and they will have greater capability to control the variability that natural materials will always exhibit. With proper controls the consumer should benefit. So far so good, but the choices we make in regulating the use of the technology will probably be the rate determining step, rather than the development of technical capabilities. Just because we can do something does not mean we should, or that it will be legal. Using a simple model of the Food Chain, we will examine past and future cases where genomics make an impact, and examine some of the social issues this pervasive technology will bring to the surface.

INTRODUCTION

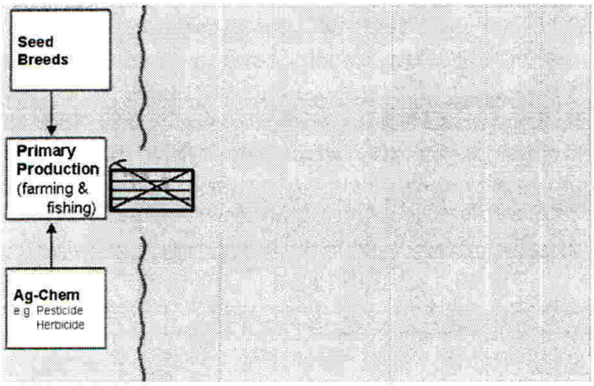
We begin by the definition of some terms, and the most important is to be clear as to what the Food Chain is, and how it works. In modern society it is a complex interacting set of competitive businesses, many of which are multinational, with the annual financial turnover equivalent to the Gross Domestic Product (GDP) of a small European nation state. At the other end of the scale we see family based small farms threatened with negative income, and street vendors of homemade foods.

Likewise, the single largest food product volume in the UK is the humble sandwich, but this is made in premises as small as an owner occupier restaurant, and as large as a robotised factory. How can we match the capabilities and potential of genomics with the vested interests of all these groups? A model is required.

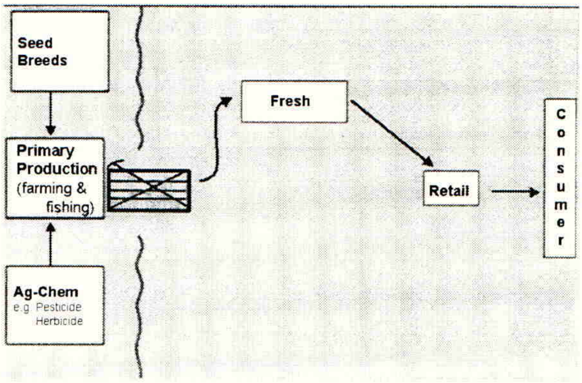
Secondly, in recent months genomics has become almost synonymous with GM Food. Whilst this is the vital topic which must be considered here, the capabilities of genomic technologies are important, even if no GM food were ever produced or consumed.

THE FOOD CHAIN MODEL

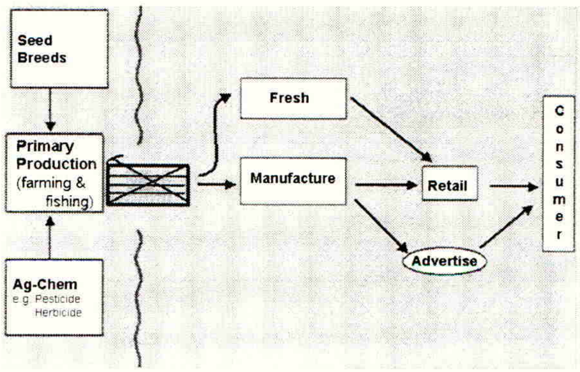
1. Within primary production, organic or conventional, specialist industries exist to provide raw material (seed and livestock) which are converted to higher added value products. The conversion require inputs to promote growth (feed and fertilisers) and techniques to eliminate competition (herbicides, pesticide, antibiotics etc). The farmer, however, is constrained not just by competitive profit making but by the intervention of subsidy designed to protect against the disadvantages of geographic location and climate.



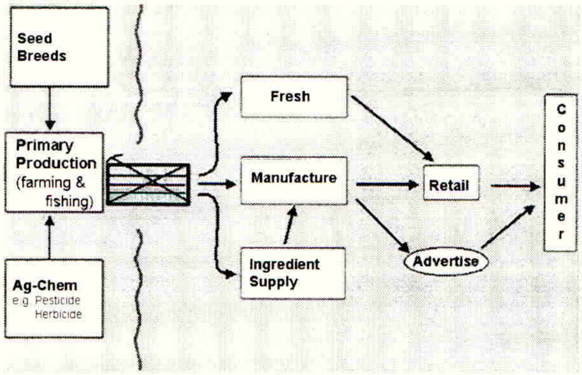
2. After the farm gate, the traditional and common chain is the fresh produce market, involving minimal processing but necessarily short distribution times or sophisticated preservation processes.



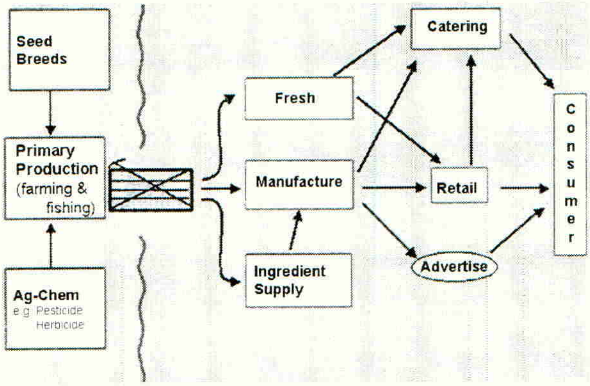
3. Some foodstuff always necessarily requires processing (e.g. Cereals → bread, milk → butter and cheese). This involves specialist technology but can add convenience and diversity, and when coupled to branded products can be of direct appeal to the consumer.



4. The modern Manufacturing process also requires Ingredients (flavours, emulsifiers, enzymes etc) either produced in-house, but most often supplied by specialist businesses, wholly dedicated to this "non-distributive" function.



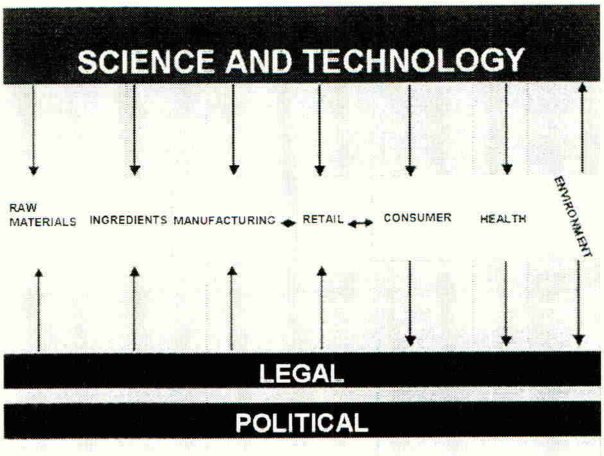
5. All of the activities developed so far imply that the Consumer both chooses and prepares (or assembles) the components into a meal or snack. In fact the fastest growing sector is Catering, where all the consumer is left to do is the delights of Choice and Consumption.



So we have a model, but what are its dynamics?

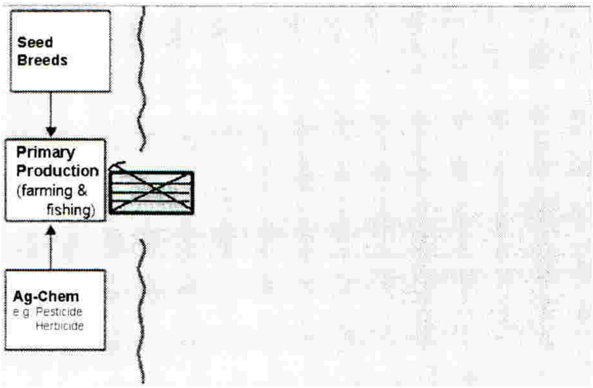
Firstly, apart from commodity agricultural produce, controlled by tariffs and various forms of open or hidden subsidies, the engine is driven by competition for profits by players within the Chain and their competitors in each function. Margins are low and until recently all business was driven by least cost production at the point of sale. The supply chain therefore has tight agreements between 'players' and is reluctant to instigate change. Its products are potentially lethal, so legislative control of best practice is exercised in most countries, with a sophistication largely determined by their economic capacity in non-food industries (developed versus developing world).

It becomes obvious that every part of the Chain will be influenced by new science and technology but that legislation will go hand in hand with its introduction.



Now that we have the 'players' and the rules of the game, we can examine how genomic technologies will be regarded by each. With such tight coupling, but with competitive interests, we can predict some dissention and also note that the line of least resistance will give rise to the fastest adoption of the technology.

INSIDE THE FARM GATE



Let us deal with the big issues first. Much of the current controversy on GM foods relates to the production of plants better equipped to protect themselves against predation (Bt varieties) or those designed to fit with herbicide management systems (Round up Ready). The debate is not really about whether they work but about whether the technology raises other risks to health or the environment. Unfortunately, the baseline reference points are the issue rather than the technologies themselves. Who knows whether gene flow from artificially mutated genes during "traditional breeding" is significant or whether the 'precautionary principle' is adequate? These have been the rules of engagement for varietal breeding for a long time. Of course it is possible that engineered plants constructed to resist all pests and herbicides would have a greater environmental fitness than current crops, or produce such species by out crossing, but to believe we can create such performance by design or accident over estimates scientists capabilities. A case by case analysis is the only sensible way forward.

The real benefit of genomics, is a much more systematic analysis of why our existing varieties succeed, and greater targeting towards more efficient production of varieties by traditional or modern biotechnology. But what are the future targets? Since farming began, the objective has been to produce edible materials cheaply and efficiently. i.e. yield of crops of known downstream use in the food chain has been the target. For much of the world, where population growth is occurring this is still the target and will remain so for the foreseeable future. Note also that "commodities" usually relate to seeds, the form of plant material which biology has been evolved to produce ambient stability over long periods. Even then it is not consistent. Why could not a future target be improved STORAGE and TRANSPORTATION STABILITY, an equally important affect as Field Yield?

The problem becomes even more obvious when the commodity is not a seed but a whole fruit. The optimisation of field yield must be developed locally (try growing tomatoes optimised in

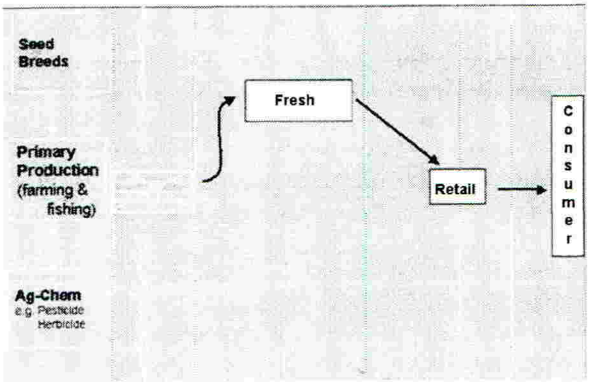
California in a Brazilian plantation where the ecological pests are totally different). With such unstable products, post harvest decay is a critical yield issue. The distribution of genomics technology into the hands of the breeder, who can relate field traits to economically relevant performance is vital.

We considered plant material first because this provides the basis for both human and animal food. Inside the farm gate, animal production is itself a profitable business, together with the by products such as milk, hides or wool. Again, direct genetic intervention meets with public concern, but AI techniques, cloning and surrogate technologies will be more easily accepted because the technologies can be related more directly to human procreation, where benefit is better understood.

Genomics has already benefited the food chain. The identification of genes associated with PSE in pork already allow improved breeding practice. It is a pity that these benefits have not had greater publicity. Therefore, gene mapping of breeds of most livestock is already producing a quiet revolution, not only in yield but in final eating quality.

Finally, what is the future for the herbicide, pesticide and infectious disease control. It is almost a biological inevitability that free trade, and global transportation will pose new problems to primary production. The success of the 'chemical industry' in the past has been a contributing factor to the population growth, but microorganisms can travel with us and mutate much faster than we can. The key issue is to transfer the capabilities of genomics to all societies that need it. In many examples this is the developing rather than the developed nations. [It is ironic however, that the tightest legislative control on food borne microorganisms is operated by the USA. Not surprising however when the size and importance of their farm based economy is considered.]

THE FRESH CHAIN



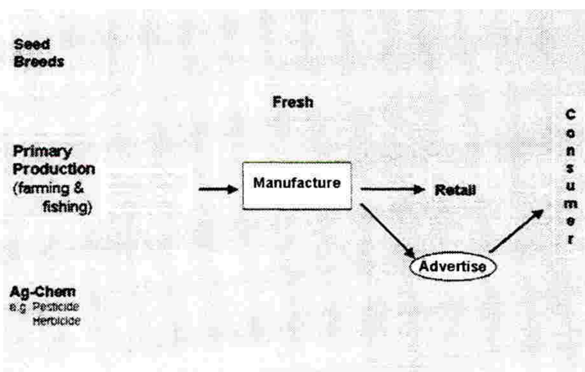
Quality is as important as cost, and traditional breeding produces firmer tomatoes, sweeter peas, transportable melons etc. The major problem concerns storage and transportation of already acceptable produce. Advanced nations can contemplate frozen storage, modified atmosphere packaging and even high pressure pasteurisation, but the majority of the world still takes its raw food to market and slower post harvest deterioration would be a major advantage. This involves the detailed control of biochemical processes which relate to multigene function. Traditional breeding may achieve it, but the selectivity obtainable by understanding gene expression and control of "metabolomics" post harvest already shows great promise.

The problems in implementation are that these are complex scientific phenomena, fresh produce involves an enormous variety of species of plants (and animals) and the consumer sees only a marginal improvement on what they obtain now. No large benefits and profits can be identified by the private sector, so research investment is low.

A slightly more positive trait is flavour enhancement and more positive still a positive health benefit claim. Unfortunately, we still know remarkably little about the origin of health benefits from long term feeding. As a result, we will continue to see "bandwagon" effects, where the newest secondary metabolite showing some correlation with disease prevention will be pushed for all it's worth.

Nonetheless, we can expect significant worldwide activity relating to the genetic control of secondary metabolites and quality traits.

MANUFACTURING INDUSTRY

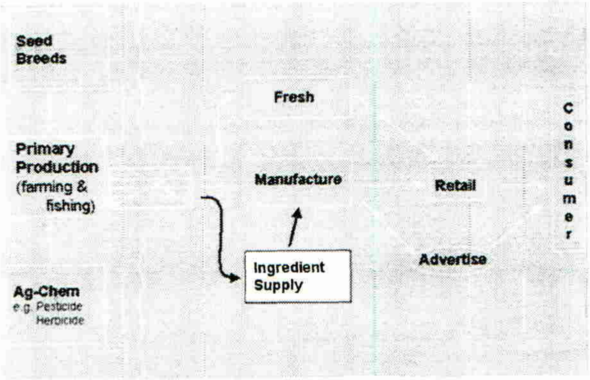


All food processing was developed empirically. In the last 50 years, due to the growth of large scale manufacture, engineers chemists and biochemists have laboured hard to untangle the various phenomena necessary for processing and their effect on raw materials. The problem has always been the separation of variables, since food raw materials contain thousands of polymers (proteins and carbohydrates) and small molecules (sugars, flavours, emulsifiers etc). Genomics has begun to enable that process to begin. For example, a few key proteins in wheat can be knocked out or enhanced, simplifying and accelerating studies of bread manufacture. The corollary, that wheat could be genetically engineered to improve processability is obvious. There are as many examples of this benefit of genomics as there are food types. Once again, however, we must recognise that the benefit accrues mostly to the manufacturer. The consumer sees more of the same (but with GM on the label in EU).

There is no need to be pessimistic about the impact of genomics, however. Such studies of the selected functional roles of food components, linked to marker assisted breeding will identify targets for QUALITY and PROCESSABILITY improvements in many crop raw materials and some are already identified

e.g. starch quality traits - thickener/stabiliser function
tomato cell wall breakdown - paste and sauce performance
connective tissue proteomics - tenderness in meat
hormone regulation - growth rates of everything

THE INGREDIENTS INDUSTRY



If we equate Food Manufacturing to the polymer and textiles industry, then Ingredients is the fine chemicals business. Product volumes are lower, but profit margins are much higher.

The Manufacturing industry increasingly depends on specialised ingredient supplies of bulk materials:-

fats
carbohydrates etc

and a multitude of highly functional minor components

flavours
emulsifiers
stabilisers
enzymes etc etc. Many of which are extensively safety tested - and as a result are given E numbers.

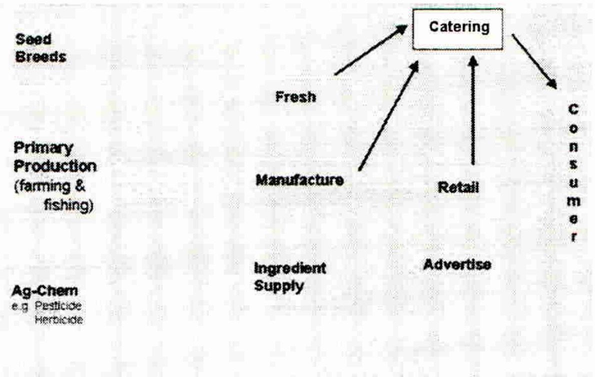
The pressure is for more natural components but simultaneously more functionally active compounds as process aids, product quality improvers. Really innovative ingredients for radical change is a contentious area, but the potential for developments and new profits are considerable. This is the area where "cell factories" will become increasingly significant.

Biology can execute reactions and synthesise molecular species with a sophistication unobtainable by organic chemistry. Using genomics and the emergent other 'omics' we can expect to understand new reactions and catalysts and enhance them in vivo or in vitro. There are metabolites with functions not yet achieved by organic synthesis, many of them related to stressed states such as drought, salinity and temperature, which the industry would like to obtain, and hence explore their performance in foods.

The interesting point is that this is already in progress AND using biotech methods. Most industrial and food processing enzymes are produced by transgenic routes. Perhaps the reason for the absence of protest from antagonist to GM technology are that these ingredients are produced in containment conditions - or is it just that we like our beer and cheese!

I believe this area will grow continuously as new process aids, antimicrobials and "health benefit" agents are discovered and demanded. Nutraceuticals will develop, together with the consumer "pull" for novel ingredients from natural, under exploited crops. The latter will have some implications for farming, but whether the potential for large scale novel sources of oils, carbohydrates, speciality proteins from GM plants will emerge depends as much on politics and economics as our new genomic technologies.

CATERING



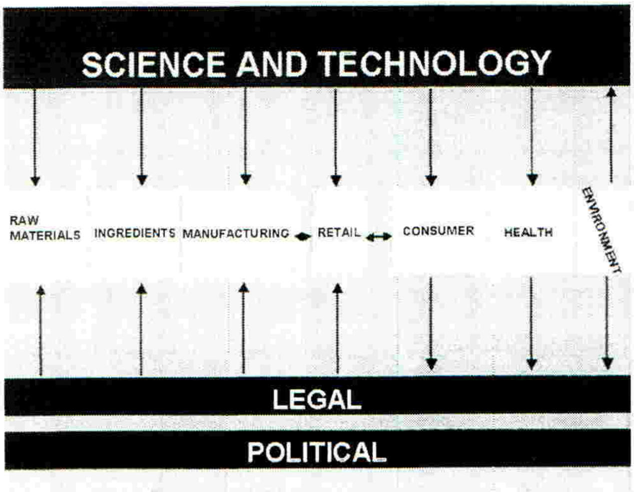
All of the foregoing case studies come together in the production of finished meals and snacks. Unfortunately, caterers, like retailers respond directly and immediately to consumer demand even when not entirely logical. We see disclaimers for GM foods alongside allergen warnings.

In future we could hope for

"All our food has been genetically manipulated to remove known allergens."

Unfortunately, this is not likely to be seen. We have the scientific capability, but the allergen free market is small and the research would be expensive, so progress will be slow.

SAFETY AND REGULATION



One issue that all players in the Chain agree on is that Safety is good for business. There is constant debate on how regulation should be enforced, but this is a lesser argument.

One of the greatest (hidden) benefits of Genomics in the Food Chain has been the identification of microbial types, rapid detection of contamination, and the molecular biological origin of stress resistance and recovery of microorganisms. This allows better hazard analysis, tighter process and raw material control and much greater confidence in the distribution system. (The average modern conference on food microbiology and spoilage is unrecognisable compared with those of 10 years ago.) This knowledge leads to improved legislation and enforcement which is of benefit to everyone, and a great many of the modern cook-chill or prolonged ambient stable products found in our stores are as a direct result of this collaborative process between private sector and government research. Retailers are much maligned for simple profit taking, but they have been in the forefront of developing and setting safety standards for raw materials, processing and distribution, much of which is now firmly based in genomics.

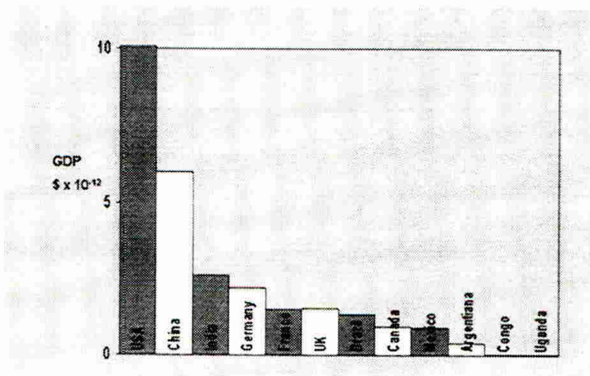
With regard to control of direct GM modification of food, the science that allows its implementation is also capable of monitoring its presence, and we expect a proliferation of gene fingerprinting methods capable of ever more greater accuracy in its detection. With legal limits in place, the financial significance of being "within the specification" is enormous, so support for method development will be a constant race between the public (legislation/enforcement) and private sector (implementor).

The upside to this inevitable development of genomic based detection methods is that they can be equally well applied to authenticity testing and traceability. Whilst the Chain approves of safety it also approves of maximising profits. This can either be done by upgrading cheaper raw materials, or expounding the provenance of expensive ones. Both need better and cheaper traceability, the former to weed out sharp practice and the latter to reward the honourable.

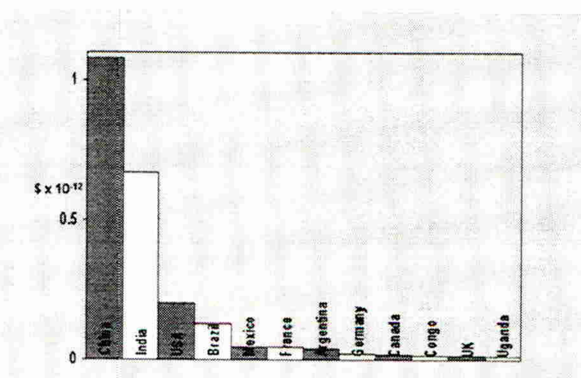
CONSUMERS

Everyone here will be aware of GM issues and public awareness, and will no doubt have strong opinions. Having lectured to many groups, I would summarise the consumers view that they would like to know more, feel a lack of control over what they do understand to be a powerful and useful technology, and are prepared to consider issues case by case. BUT they hear more about potential risks than benefits and are therefore unconvinced. They have some just cause. New technology does not automatically produce a new consumer benefit, and in many of the cases I have outlined, the actual perceived benefit will be small, to a population where food is cheap and almost overwhelming in variety. However, significant new benefits are there. We must be more selective in our targets and encourage the Chain to demonstrate them.

We hear much about the divide between consumers in developed and developing world. However, in terms of the acceptance or otherwise of GM technologies the divide is better correlated with nation states where agriculture is economically significant and those in which it is not. The following graph shows the value of income generated for key countries.



Wealth of Nations 2001



Value of Agriculture 2001

This is not related to the number of employees in the agricultural sector, but it does indicate the political significance and therefore the national interest in remaining competitive. Our problem in Europe is that the consumer has heard more about surpluses than shortage and our use of subsidies to maintain price structures rather than lower them means that the consumer has paid twice. Once for the CAP costs and again in the supermarket. Even with this in mind, the percentage of personal income spent on food is lower than ever in Europe and when they see a benefit (real or imaginary), consumers will pay more for their food. The startling growth of organic foods and dietary supplements is proof that cost is no longer the only criteria for purchase. Not a good platform to argue that the new technology is necessary for cost reduction, and is to their benefit.

In 1994, the Technology Foresight reports made a number of key predictions of significance here.

1. Genome Studies - "The major hurdle to progress is consumer acceptability. Whether or not transgenics are accepted into the food chain, scientific developments will provide vital tools"

2. Health - "...... research on the links between food metabolism and genetic predisposition will require further (public sector) support, owing to the complexity of multigene interaction."

The first has been overtaken by events. The second remains valid and will best be served by genomics not only of food materials but of human diversity as well.

POLITICS AND ETHICS

In conclusion, the title of this talk is the Impact of Genomics on the Food Chain. I have attempted to demonstrate that genomic technology is here to stay and it will have a massive impact on the practices of the Chain even in societies where GM foods are opposed. We must recognise however, that the future is now a matter of international law, labelling, trade agreements and shear political negotiation between major trading blocks.

In Europe it has been argued that labelling will set us back years in the public acceptance of GM Foods, and the earlier case of irradiation has been quoted, where a skull and crossbones on packaging virtually eliminated the consumer acceptance of the technology, which promptly when "underground".

I have argued that the opportunities presented by genomics are in a different league, both with regard to the extent of the technology and the many and varied risks and benefits. We must recognise both of these deciding issues, and the consumers' capability to judge what is best for them, wherever they may be. Furthermore, differences of belief in the issues related to interference with natural processes remains a major issue and we should at least respect the rights of individuals to exercise their personal choice.

Meeting consumer demand for food safety, quality and environmental protection

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ABSTRACT

Consumer's expectations are high. They want food to offer all the qualities needed to fit their lifestyle and values. This means good taste, convenient preparation, and health enhancing properties, produced in a manner consistent with environment care. Consumer knowledge and perceptions of food and agricultural issues in the US and Europe, indicate that to meet these expectations, more effective communication is needed.

CONSUMER FOOD EXPECTATIONS

Convenience

Consumers are increasing their use of convenience foods. The trend toward partially prepared food, strong in European markets, is growing in the United States. The top four attributes of food US consumers say they would definitely or probably try are: 'ready to eat'; 'heat and eat'; 'packaged for on the go'; and 'no utensils required' (Sloan, 2003). According to the Grocery Manufacturers of America, food category growth in 2002 compared to 2001 increased in frozen food (3.7%), especially dinner items (3.5%), snacks (2.8%), sweets (2.5%) and beverages (2.1%) with a decrease in purchase of general merchandise (3.5%) and minimal growth in basic ingredients (0.5%) (Times & Trends, 2003a).

The greatest number of successful new products in 2002 featured unique flavours (65) followed by extra convenience (42) (Times & Trends, 2003b). Tomorrow's high quality convenience foods with sufficient shelf life for profitable marketing require innovation such as modified atmosphere and non-thermal processing technologies. To realise these benefits, the public must be comfortable with the safety of the technology and the food.

Health

The most widely publicised issue in the nutritional arena in the United States is our tendency to consume more calories than we expend. Guidelines for health are reviewed and modified every five years. The newly formed United States Department of Agriculture Dietary Guideline Committee includes several experts on weight control. Meanwhile, some popular writers blame the problem of the weighty public on the food industry, especially fast food chains for offering high calorie food that tastes good. Some consumers have initiated legal action against the food industry. To date, these suits have been dismissed, however about one third of consumers believe the food industry is at least somewhat responsible for the growing problem of excess girth (Saad, 2003). Opportunities are great for low calorie foods that deliver full calorie flavour.

According to David Byrne, European Commissioner for Health and Consumer Protection, Europeans are also facing a "disturbing increase in obesity, in particular amongst young people" (Byrne, 2003). As in the United States, Byrne notes that Europeans are less physically active, work in offices, prefer elevators to stairs and have replaced cycling and walking with the car. To address this problem, Byrne advises that people consider the quantity and quality of what is eaten, and increase physical exercise. He believes mandatory nutritional labelling of processed foods will help consumers make better-informed choices. Furthermore, Byrne indicates that he will endorse increased use of health and nutrition claims on food. The purpose of this enhanced labelling is to provide greater information so consumers can make choices based on clear and accurate information. He favours a science-based validation of food claims to ensure the potential benefits are properly justified.

Some claims in the marketplace are vague and meaningless. To address this problem, Byrne recommends that claims fit into two categories:

- they may describe the role of nutrients or other substances based upon long-established and non-controversial science;
- they may identify a reduction of the risk of specific diseases (Byrne, 2003).

Scientific evaluation and pre-market approval would always be required. Furthermore, Byrne recommended that authorised claims with specific criteria, such as "high fibre" or "low fat" be permitted.

This system is much like that in place in the United States. Nutrient content claims refer to the level of specific nutrients in the product. Terms such as "high" or "low" are specifically defined. Claims are also permitted that relate consumption of a specific food component to health. Currently over 12 health claims have been authorised including relating the consumption of calcium to reduced risk of osteoporosis and diets high in fruits and vegetables to reduced risk for heart disease and cancer.

Mandatory labelling and health claims have lead to product innovation and a wider choice of foods that meet specific nutrient requirements. For example, ice cream and frozen yoghurt in US markets offer a range of calories, fat content, calcium and vitamin A to suit consumer dietary and flavour preferences. This variety has not reduced obesity, but consumers are empowered to make informed choices. Over half of consumers interviewed indicate they pay a fair amount, or a lot, of attention to nutritional recommendations. (Saad, 2003)

Health benefits provided by food

While not all consumers consult nutritional labels, consumers are attuning to the potential health benefits food can provide. In 2002, eight out of ten people indicated they tried to prevent a condition through food purchases (Sloan, 2003). Furthermore, more than 70% of consumers indicated that they believed certain foods will improve their digestion and reduce their risk of diseases and 50% think that certain food could reduce their need of medicine (Health Focus International, 2001).

The food industry and nutrition community has coined the term "functional foods" or "nutricuticals" to describe foods with specific health benefits beyond basic nutrition. Consumers find these terms confusing and too technical, preferring "personalised" or "individualised" nutrition. Studies in the US and Europe indicate growing interest in foods with enhanced health properties. Scandinavian consumers expressed an interest in product healthiness, taste, familiarity, convenience and price (Urala & Lahteenmaki, 2003).

Food manufacturers speculate that the negative publicity surrounding dietary supplements in recent years has slightly dampened the demand for functional food (O'Donnell, 2003). Nevertheless, surveys and sales indicate that functional foods hold great potential. Items of greatest importance include soy protein, calcium, dietary fibre, omega fatty acids and probiotics or specific bacteria that enhances health. Soy protein may reduce the need for oestrogen in post-menopausal women and may reduce the risk for heart disease and certain cancers. Adequate calcium reduces the incidence of osteoporosis, a debilitating bone disease that affects 50% of the women over 50 years. It may reduce the risk of high blood pressure and may reduce the incidence of certain cancers. A diet high in fibre enhances colon health, may reduce the incidence of colon cancer and increase the feeling of satiety. Omega fatty acids may protect against heart attack. Probiotic cultures enhance the immune system, guard against traveller's diarrhoea, may protect against pathogenic bacteria, reduce yeast infection in women, may reduce high cholesterol, may reduce the incidence of cancer, reduce some allergic reactions and may aid healing after exposure to radiation. (Sanders, 2000; Sanders, 1998)

Manufacturers believe that the greatest challenges for functional food is lack of consumer awareness (53%), lack of scientific validation (43%) as often the evidence is strong but not sufficient to meet the Food and Drug Administration requirements, lack of a clear definition (41)% and flavour problems (37%) (O'Donnell, 2003). For example, consumers accustomed to the flavour of dairy-based yoghurt products may not find the flavour of soy-based alternatives acceptable.

When asked to forecast the growth or decline of functional foods in the next two years, on average, respondents projected a 30% increase, with only two of 142 food manufacturers expecting a decline (O'Donnell, 2003). Natural ingredients offer the greatest opportunities, according to manufacturers however there is no clear definition for natural. Cardiovascular health and cholesterol reductions are also seen as meeting consumer demand. Weight loss, reduction of cancer risk, and foods that increase energy offer marketing opportunities. While there is interest in organic ingredients, manufacturers note that organic ingredients may be significantly more expensive, the source of some ingredients is inadequate and scientific validation of organic benefits is lacking.

Eat more fruit and veg

Fruits and vegetables are regarded as health promoting, but consumption has not increased as rapidly as health professionals and the industry would like. In the United States, produce consumption is promoted through a nation-wide "5 a Day" programme. This widely endorsed programme advises consumers to eat five to nine servings of fruits and vegetables daily. While awareness of the program has gradually increased, fruit and vegetable consumption declined 14% during the last ten years (Linden, 2003). Vegetable consumption dropped 18% while fruit consumption decreased 11%. In 2002, only 20% of US consumers actually ate five servings of fruits and vegetables a day. Men are more likely to consume five servings than women are, with 50% of men over 65 years consuming the recommended amount. The worst non-achievers are families with children, with 74% of families not eating four servings per day.

Fruits and vegetables contain functional ingredients that contribute to health beyond basic nutrition. In additional to vitamin A, C and E, they contain dietary fibre and antioxidants that reduce the risk of cancer and heart disease. Why, then is consumption not higher? The drop in consumption may be attributed to a decline in the traditional meal pattern and an increased preference for convenience. Side dishes are the primary contributor to vegetable consumption in the American diet, but serving side dishes declined 25% in the past 18 years. The increasing demand for convenience resulted in fewer "at-home" meals and fewer homemade dishes. In 2001, 66% of in-home dinners included at least one fresh product, while in 1986, 77% of dinners included at least one fresh product (Linden, 2003).

What strategies can be used to increase consumption? Those eating the recommended amount ate produce "as is" and incorporated fruits and vegetables into their main meal rather than exclusively through snacks (Linden, 2003). Offering a wider variety of produce in the workplace and school could contribute to higher consumption. Convenience may play a role. Just as offering ready-to-eat carrots significantly increased carrot consumption, peeled and cut fruits and vegetables beyond that currently in the marketplace may open the door for greater use. Research is on going on the use of low-dose irradiation, high pressure processing and other methods to produce high quality ready to eat produce items.

ENVIRONMENTAL PROTECTION

Consumers today value protection of the environment. Some see organic production as contributing toward this goal. Many United States consumers select organic because they believe organic products are safer, better for the environment, or more nutritious (Health Focus International, 2001). There is little scientific information to support these generalisations. This category of products has grown markedly in recent years. Organic sales in the US grew by 20% in 2002, to $9.7 billion dollars. To put this quantity in perspective, the market value is about half the amount spent on salted snacks, $18.8 billion and on fortified foods and beverages, $20 billion (Sloan, 2003). Awareness of organic food is high but penetration remains at about 40% of households suggesting those who buy organic are buying more rather than new customers switching to the category.

Use of recombinant DNA (rDNA) technology or genetic engineering offers further potential to protect the environment and produce foods with characteristics consumers' value. This technology can reduce use of pesticides and facilitate no-till production (Fawcett & Towry, 2002; Phipps & Parks, 2002). Applications in Hawaii demonstrate that the rDNA techniques can protect plants from viruses. Plant breeders have used rDNA technology to develop corn that is nutritionally more dense and easier for animals to digest (Mazur, *et al.*, 1999).

Scientists are also developing feed with lower levels of phytate; this has environmental ramifications because it will reduce phosphorous, nitrogen and odour from animal waste (Mazur *et al.*, 1999). Plants have been developed that remove high levels of salt from the land, thus opening the potential for bioremediation (Zhang & Blumwald, 2001). Human foods can be produced with improved nutritional characteristics, lower levels of natural toxins and increased quality (Dowd *et al.*, 1999; Gura, 1999). In the future, people with allergies may find the proteins that trigger allergic reactions have been removed, allowing consumption of previously prohibited foods (Institute of Food, 2000).

European consumers

It is widely believed that European consumers are very resistant to products modified by rDNA technology and indeed statements on menus and in supermarkets that advise consumers that genetic engineering has not been used, enforce the notion that there is something risky about genetic engineering. Only about half of European consumers are aware of many of the applications of biotechnology. (INRA & (Europe)-ECOSA, 2002) Slightly over half, 56% are aware that genetic modification could be used to make plants resistant to insect attack. About half are aware that these tools could be used to detect diseases or prepare human or animal medications. Only 28% knew biotechnology could be used to clean toxic spills.

Europeans considered some applications of genetic engineering beneficial. People were asked to rate on a scale of 1 to 4 if an application was useful, risky, or should be encouraged. The applications considered most useful were cleaning toxic spills, rated 3.24, using genetic material to detect disease, rated 3.4 and preparing human medicines rated 3.27 (INRA & (Europe)-ECOSA, 2002). Each application was considered to have some risk. Those viewed most risky were food production, rated at 3.0 and the cloning of animals to produce medicines and vaccines, rated 2.92. Even though applications were considered risky, people felt they should be encouraged. Those applications with the highest rating for "should be encouraged" were cleaning of toxic spills (3.17), cloning animals whose milk can be used to produce medicines (3.01) and detecting hereditary diseases (3.01). Production of foods received a rating of 2.19.

While some may interpret the relatively low score for food applications as meaning that Europeans are not supportive of food applications, an examination of the question consumers were asked indicates that another interpretation is possible. Benefits of genetic modification of food were described as to "give them a higher protein content, to keep them longer, or to change the taste." These benefits may not be very appealing to European consumers. Food applications that offer more compelling benefits may be better received.

Information about benefits may not be sufficient to enhance the acceptance of rDNA products. Consumers lowered their rating of the flavour of cheese when it was labelled as genetically modified and only two out of five cheeses were chosen to take home (Lahteenmaki, *et al.*, 2002). Danish researchers found that providing information on genetically modified products, even though the information was positive, sensitised consumers to any negative attitudes they may have about the process (Grunert, 2003). They suggest that direct experience with a product that provides a clear consumer benefit would be most effective in increasing acceptance of products produced by rDNA technology. Furthermore, they advise that contact with the market and opinion leaders should begin as soon as possible before strong and deeply rooted attitudes have been formed.

Benefits, safety and trust

Is it already too late? Is acceptance dependent on benefit, safety and trust in the information source? George Gaskell and fellow researchers found that both supporters and opponents to food applications feel insufficiently informed about the topic (Gaskell, *et al.*, 2000). Support is more trusting of the government and industry and less trusting of environmental groups. Even supporters, however are concerned about the "unnaturalness" of the technology (Gaskell *et al.*, 2000). Other concerns centre around what is seen as inappropriate haste, i.e. proceeding with developments before appropriate tests have been conducted (Gaskell, 2000). People are worried about who is looking after the public interest, with some seeing too close an alliance between governments and industry. The government is seen as adopting the dual role of regulator and supporter of biotechnology. As government praises the technology, people think that profit may be placed ahead of safety. Similarly, scientists are seen as speaking from a vested interest rather than the public interest.

Each of these concerns can and should be addressed in a proactive manner. What is unnatural? Is there a difference between facilitating or blocking a gene that expresses a characteristic compared to inserting a gene from another organism? Is moving a gene within related species acceptable? How fast is too fast? Genetic modification has been studied for years and many tests have been completed to demonstrate freedom from ill effect. When has sufficient testing been completed? When the 1999 Eurobarometer study was completed half of the people were not aware of the range of applications, they certainly were not aware of testing procedures or results.

It is not reasonable to expect the public to be aware of testing details, rather attitudes may reflect the trust in regulatory bodies, scientists, and other groups. Regarding agricultural issues, consumer associations were recognised as trustworthy by the greatest number of Europeans at 79%, followed by farmers at 72%, friends at 70% and agriculture experts at 68% (Gallup & Europe, 2000).

Who is seen as trustworthy?

In the area of genetic engineering, consumer associations lead the list of trustworthy sources of information at 26% followed by medical organisations at 24% (INRA & (Europe)-ECOSA, 2002). Trust in government bodies is quite low, at 4% for international authorities and 3% for national bodies (INRA & (Europe)-ECOSA, 2002). In a separate study, the government, journalists, and European institutions were identified as least trusted by 59%, 45%, and 43% of consumers respectively (Gallup & Europe, 2000).

IMPLICATIONS

These findings suggest a need for effective communication regarding scientific information on health and nutrition, the role of new food processing technologies, the potential benefits, the concerns and the safe guards related to newer methods of production such as those made possible by rDNA technology.

Communication begins by hearing consumer concerns, assessing their knowledge, using information sources they trust and prefer, delivering the message and assessing the message effectiveness to address consumer concerns. The message should acknowledge what is known, what is not known and not to overstate the benefits. It is also important to maintain an on going dialogue rather rely on a single communication.

While consumer associations are considered trustworthy, scientific organisations trade associations and regulators each has a responsibility to share their expertise with the public. Educational materials could be directed toward children, adults or special audiences like farmers and supermarket personnel. Educational programs should be delivered in the school, at community or service group meetings, at the fair, through the media, or by person-to-person discussions.

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Balancing bio-diversity and agriculture

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ABSTRACT

The issue globally is seen as a 'trade off' between biodiversity and intensification against a background of the need to produce about 50% more food by 2030. Expansion of the area cropped globally would seriously impact biodiversity but there are also many problems with the other option, intensification. Evidence concerning cereal-ecosystem weeds, insects and birds is examined from a continuous 36 year study of biodiversity on 62 km² of arable farmland on the Sussex Downs, UK. The data show a resilient cereal ecosystem with no obvious pesticide treadmill effects and associated studies are showing that practical measures can be taken to limit the damage to biodiversity caused by the intensification of cropping. The developed world will have to produce more grain and export it to the developing world in order to save the rich bio-diversity in tropical forests. To be effective this must go hand-in-hand with bio-diversity conservation where the extra grain is produced.

INTRODUCTION: THE NEED TO PRODUCE MORE CEREALS

Forecasts of the number of people that the world needs to sustain have been steadily reduced over the past decade or so, but substantial increases are still expected. In June 2002 the United Nations Population Division estimated that by 2030 there will be another 2.3 billion people, or 38% more than now, even after 'factoring in' the latest HIV/AIDS projections and revised fertility declines. Latest UN estimates are that 800 million people in the developing world do not get enough food. Future populations will also eat significantly more meat and dairy products *per capita* than now and declining stocks of wild fish and bush-meat underline the need to produce more food on farms.

In summary an extra billion tonnes of cereals will be needed annually by 2030, or almost 50% more than now. The problem is most acute in Asia which will have to cope with an extra 1.2 billion people by 2030, needing 60% more grain than now (FAO: 2003 *World Agriculture 2030*).

So how are the extra cereals to be provided? Alternatives would be to increase the area cultivated globally by 320 million ha, approximately equivalent to 100 times the current cereal growing area in the UK, or increase the world cereal yield from 3.1 to 4.6 tonnes per ha, equivalent proportionately to the astonishing increases in the EU15 in the two decades up to 1990. Even with an optimistic scenario of increasing yields by employing three times as much fertiliser and doubling the present amount of irrigation Tilman (1999) estimated that 20% more land will still be needed for crops by 2030 and some land used today will not be useable by 2030 due to urbanisation, salination and water shortages.

More intensification (greater production per unit area) means less need for extensification (unit production over expanded area) and *vice versa*. Both processes are necessary and both adversely affect biodiversity. This paper aims to strike a balance that reduces the overall impact, whilst not compromising the production of the extra food needed.

BIODIVERSITY: THE PROBLEM WITH CONVERTING MORE LAND TO AGRICULTURE

The losses from various ecosystems to agriculture have recently been quantified by using the Global Ecosystems Database held at Boulder, Colorado, in particular the classification of croplands by Olson *et al.* and of original habitats by Holdridge. This study showed that 71% of the total cropped area had originated from forest (Pimm 2001).

Considering such factors as the unsuitability of boreal and mountain forests, re-afforested areas, for example in India and China, and long term limitations regarding irrigation it is clear any future expansion of the croplands must primarily come from tropical forests in the Amazon and Congo basins and in Borneo, containing vast numbers of species that are not yet threatened (Myers *et al.*, 2000).

The distribution and densities of birds are better known than other plants and animals and amongst birds the game-birds are arguably best known. In their case any expansion of the arable area would involve far more species, especially threatened species, than are currently threatened by agriculture (Table 1).

Table 1. The world's gamebirds: current distribution of species and of species threatened according to major habitat types and changes in habitat area 1961-2000

Habitat	Habitat change 1961to 2000	Number of species	Threatened species
Cereal ecosystems	+25%	32	3%
Grasslands	+15%	89	18%
Forests excluding boreal	-11%	198	47%

Notes: Threatened is vulnerable or worse in the IUCN classification. Sources are FAO/World Bank report *Farming Systems and Poverty* (2003); FAO's *State of the World's Forests* (2003); Madge & McGowan (2002) and Del Hoyo *et al.* (1994); snowcocks, and tundra and boreal forest grouse are excluded.

FAO's "*State of the world's forests 2003*" study indicates that the agricultural land area is still expanding in 70% of countries. In this majority of countries the area of forest is decreasing whereas in countries where agricultural land is decreasing, forests are expanding. Looking back, it has been estimated that if agricultural technology had been frozen in 1961, more than twice as much cropland as now would be needed just to maintain food production at present levels and that "virtually no natural forest would remain" (Goklany & Trewavas, 2003). Freezing technology now would again threaten natural forests, with the position most serious in Asia.

BIODIVERSITY: THE PROBLEM WITH HIGHER YIELDS

The long term study on the Sussex Downs

The 62 km² study area and methods have been explained in detail in a number of publications (Potts & Vickerman 1974; Potts 1986; Aebischer 1991). The research was instigated to discover why the grey partridge (*Perdix perdix*) was declining and how numbers could be restored. It soon became obvious that very little was known about the ecology of the habitat of this bird: the cereal ecosystem. Given the importance of the habitat to mankind this was astonishing.

The essential point so far as this paper is concerned is that methods of sampling invertebrates (600+ species) and cereal weeds (150 species) were established in 1970 and 1972 respectively and repeated annually in the same way in 100 cereal fields in the third week of June. For example, insects and other invertebrates were sampled with a 1969 version of Dietrick's Vacuum Insect Net. This wore out about every ten years but was replaced not with modernised versions but with replicates of the original. Current work is reviewing all these long-term data for publication.

Species currently affected by modern methods of growing cereals: plants

Samples from individual cereal fields on the Sussex Downs typically contain 15-20% of the species that were present before herbicides were introduced (Potts 1986). Some species that were abundant in the study area before herbicides were used e.g. narrow-fruited cornsalad (*Valerianella dentata*), white campion (*Silene latifolium*), corn gromwell (*Lithospermum arvense*), shepherd's needle (*Scandix pecten-veneris*) and common hemp-nettle (*Galeopsis tetrahit*) are now rare, whereas others that were less common at that time are now virtually extinct; e.g. corn spurry (*Spergula arvensis*), pheasant's eye (*Adonis annua*), corn parsley (*Petroselinum segetum*) and cornflower (*Centaurea cyanus*).

Farmland in Britain now holds more scarce and threatened plant species than any other habitat (Rich & Woodruff 1996) species that are at last receiving the attention they deserve (Wilson & King, 2003). The situation is similar overseas (Potts, 1986; 1991) with a number of detailed studies e.g. Denmark (Andreason, *et al.*, 1996) and Finland (Pitkänen & Tianen 2001).

Rare species aside, the Sussex Downs Study is beginning to reveal a more complex picture (Ewald & Aebischer 2000). The increase of grass weeds in cereals during recent decades is of course well known, although in the Sussex Downs Study Area, where only 9 species occur, this has been contained by new herbicides, beginning with chlorotoluron in 1974 (Figure 1).

At the beginning of the study several MCPA resistant broadleaved weeds were very common, particularly chickweed (*Stellaria media*), the *Chenopodium/Atriplex* group and the speedwells *Veronica persica* and *V. arvensi.* All these species declined rapidly from about 1985 as new herbicides controlled them and this is the reason the overall biodiversity of broad-leaved weeds began to decline (Figure 1). Cleavers (*Galium aparine*) dramatically increased until about 1995 by which time it was abundant, since when it too has declined. During the past two decades a number of species that had been rare, or even absent, at the beginning of the study have increased (see Table 2) and the biodiversity has held up well despite the declines mentioned above. Some species now found in cereal crops are not recognised as arable weeds (e.g. by Wilson & King 2003) and the number of species or taxa encountered has not changed; 41 in 103 cereal crops in 1972, 46 in 111 cereal crops in 2003.

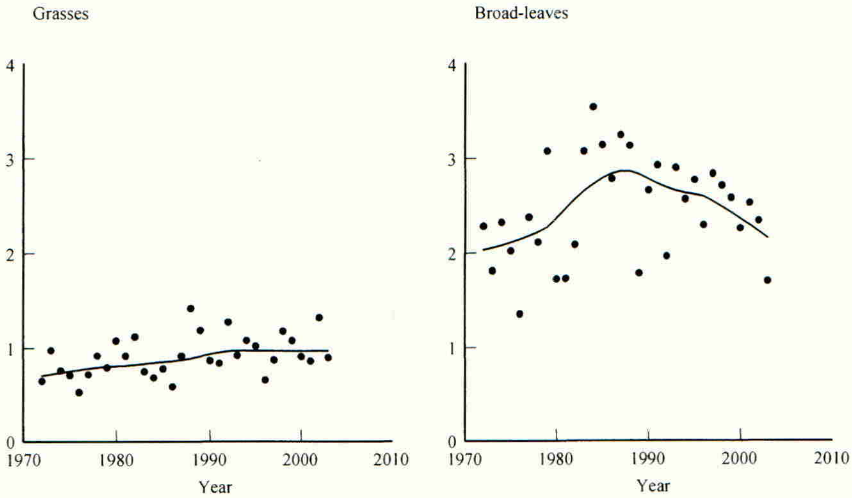

Figure 1 Trends in biodiversity (species or taxa per sample) of cereal weeds on the Sussex Downs Study Area 1972 to 2003.

Table 2. Some broad-leaved weeds that have markedly increased in abundance in cereal crops 1972-2003: Sussex Downs Study.

Species	Common name	Reason for increase
Sisymbrium officinale	hedge mustard	symbiotic with previous oilseed rape
Coronopus squamatus	swine cress	tram lines
Viola tricolour	field pansy	change in herbicide selectivity
Sherardia arvensis	field madder	change in herbicide selectivity
Papaver rhoeas	red poppy	change in herbicide selectivity
Malva sylvestris	common mallow	climate change?
Rumex obtusifolius	broad-leaved dock	set-aside the previous year
Arctium lappa	greater burdock	set-aside the previous year
Artemesia vulgaris	mugwort	set-aside the previous year

Clarke *et al*., (2003) found that one of the most important species for seed eating farmland birds in England is still knotgrass (*Polygonum aviculare* amalgamating with *P. rurivagum* see Stace 1997). On the Sussex Downs the frequency of this species in June has not changed significantly. Availability on stubbles did decline through the 1970s mainly attributable to straw-burning (Potts 1986) reversing when this was banned.

It is not known whether any of the species in the study area have become resistant to herbicides, other than black grass (*Alopecurus myosuroides*) but resistance has been increasingly reported elsewhere since the early 1980s. The first case, triazine resistant groundsel (*Senecio vulgaris*) was in California, but globally the number of resistant species has grown from 48 to 270 in the past decade (Ron Vargas, Univ. California, Davis 2001) and now includes sulfonylurea resistant chickweed in Scotland (S R Moss, Rothamsted Research, 2003).

Species currently affected by modern methods of growing cereals: insects.

Very little is known about long term trends in the insects of cereal fields, apart from the Sussex Downs Study. Following the publication of Rachel Carson's *Silent Spring* in 1962 there was widespread alarm about the status of some species of butterflies and about apparent increases in pests, evidenced by outbreaks of cereal aphids in 1968 resulting in car windscreens so dirty that wipers could not cope. Letters in the press drew attention to the lack of ladybirds.

At first the evidence revealed through the Sussex Downs Study suggested that the use of herbicides and fungicides was reducing aphid predator abundance and causing the aphid outbreaks. Several species of generalist aphid predators such as rove beetles of the genus *Tachyporus* were declining dramatically due to the use of foliar fungicides (Potts, 1977; Aebischer, 1991). By 1975, aphicide was frequently being sprayed from the air on a large scale with adverse effects on aphid predators (Potts, 1986, Ewald & Aebischer 2000). Numbers of aphids in the hot summer of 1976 broke all records, and, despite the record amounts of aphicides used on cereals, generated a huge increase in ladybirds that even alarmed bathers and featured on national TV news. Many facts were consistent with a "pesticide treadmill" of the kind envisaged by van den Bosch (1978), except that there were no further outbreaks of cereal aphids on the Sussex Downs Study Area.

From 1976 insecticides were used extensively in autumn to control barley yellow dwarf virus (BYDV) and on some farms in summer but the consequent increase in aphid mortality cannot have been the reason outbreaks ceased. First several species spend the autumn and winter in hedgerows where they are not sprayed; they decreased in line with *Sitobion avenae*, a species that winters in cereal fields. Second, the decline of cereal aphids was parallel in autumn barley (mostly sprayed, but only in autumn), spring cereals and oats (not sprayed) and autumn sown wheat (sprayed in autumn and often in summer) (Aebischer, 1991).

Taking the country as a whole spraying was less intensive in cereals than in other crops and there is no evidence of resistance to aphicides amongst cereal aphids in the wild. In contrast many peach/potato aphids (*Myzus persicae*) are resistant to organo-phosphates, pyrethroids and pirimicarb ("MACE resistance"). Presumably this has been avoided in cereal aphids through less intensive spraying than has been the case with potatoes and sugar beet.

The role of generalist predators in keeping down cereal aphids was established experimentally in the 1980s (Wratten & Powell 1991). The Sussex Downs Study has however shown that the ratio of cereal aphids to generalist predators may not have changed during the successive phases of intensification of cereal growing over the past 33 years, indeed the ratio appears to have declined, though this is not statistically significant (Figure 2). It appears the situation is under control.

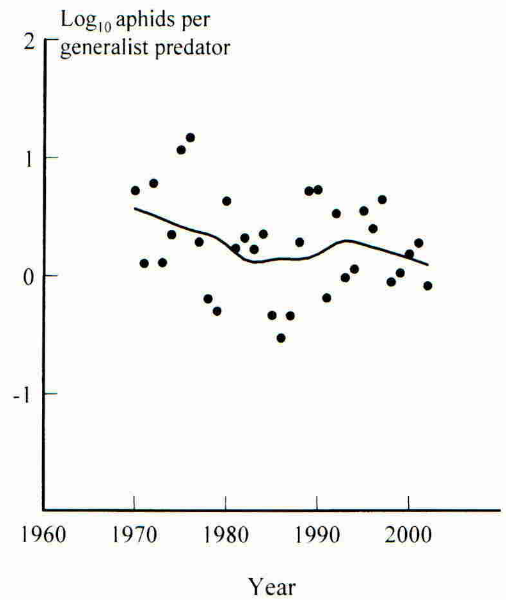

Figure 2. The ratio of densities of cereal aphids to densities of generalist cereal aphid predators in cereal crops: Sussex Downs Study Area 1970-2002.

Species currently affected by modern methods of growing cereals: birds

Since about 1972 partridge chick prey abundance has averaged about half what it was prior to the use of herbicides, although the situation has not deteriorated further (unpublished data). But during this period attention has increasingly been drawn to the decline of other hitherto common farmland birds.

In the UK a total of 113 species should be considered as farmland birds, with 99 breeding (Shrubb 2003) 69 of them breeding in the Sussex Downs Study Area at least once since 1968. Gibbons *et al.* (1993) considered only 28 of these species in their analyses and their list, minus rarer and introduced species became the 20 species of the Farmland Bird Index of Siriwardena *et al.* (1998) of which 19 are used by DEFRA in its indicator of sustainable development. Twelve of these are considered farmland specialists, eleven are declining significantly, nine are on the red list and eight of them are Biodiversity Action Plan Priority Species. So, how serious is the overall position?

During the early part of the breeding seasons of 2002 and 2003 I carried out six 2-3 hour transects on typical arable farmland on three of the Sussex Downs Study Area farms. I counted 1468 birds, of which 1005 (68%) belong to the 20 species in the Farmland Bird Index. In 1970 I had counted grey partridge, lapwing and corn bunting on the same areas. For the other species in the Farmland Bird Index I used the British Trust for Ornithology CBC and calculated the number of that I could have been expected to have seen in 1970. This gives 1400 in 1970 compared to 1005 today, indicating a decline of 30%. Few of the other 49 species that have bred in the Sussex Downs Study Area have declined and others have increased so the overall decline is about 20%.

Steep declines have been caused in many bird populations across Europe and a study of intensification effects on birds in 30 countries showed that the downturn in population trends for 52 species became marked above approx. 4.5 tonnes cereal yield per ha in 1993 (Donald *et al.* 2001). The relationship between intensification of cereal growing and grey partridge stocks in 22 countries, including the USA and Canada has also shown effects of intensification to become serious where production averaged more than about 4.5 tonnes per ha of wheat in 1983-1985 (Potts 2002).

Obviously we cannot return to yields like these, so what can be done?

RECOVERING LOST BIODIVERSITY BY CROP MANAGEMENT

Monitoring of grey partridge populations on two farms in Aisne, France shows a dramatic increase in partridge numbers despite intensive cereal growing. Whole farm wheat yields have exceeded 10 tonnes per ha during the past five years on the two farms. The increase in partridge numbers has been the result of a private initiative in partridge management, halving already rectangular field sizes to 8 ha, increasing nesting and brood rearing cover (especially on set-aside), reducing predation on nests by intensive predator control, limiting use of insecticides and feeding with wheat grain throughout the year. Cropping was with wheat, maize and sugar-beet with adjacent fields always with different crops to maximise spatial diversity. This package of management was introduced progressively from 1989 with dramatic effect (Figure 3).

Since 2001 many of the methods and results have been replicated by the GCT on an area south of Royston, Herts, UK with the first two years results in line with experience in France.

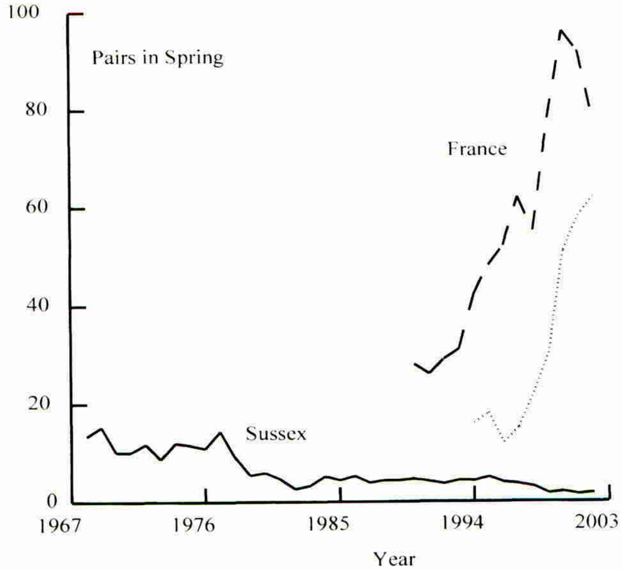

Figure 3. Trend in stocks of grey partridge on the Sussex Downs Study Area and on two farms in France subject to conservation management

This example shows that well researched, properly funded and well targeted measures can be taken to alleviate the biodiversity depletion that inevitably arises from intensification. The current Reform of the CAP creates the possibility of repeating these successes on a Europe-wide scale. Where set-aside can be used for the purpose there will be the added advantage of creating bio-diversity without reducing the production of food. In other countries, for example in the former Soviet Union, special measures are urgently needed, because many species there have not yet been impacted by intensification.

In these and other countries intensive management will not save the many important groups of birds threatened by modern cereal growing, that have large home-ranges. For them extensive management is necessary and it will have to be properly targeted. For example the Conservation Reserve Program (CRP) returned millions of hectares of cereals to grasses but exacerbated the position of the lesser prairie-grouse (*Tympanuchus pallidicinctus*), a grassland species that had already declined more than 99%, partly through the growing of cereals! (Johnsgard 2002).

CONCLUSIONS: THE FUTURE

This study has shown that the intensification of production has many advantages over extending the area cropped in preserving high biodiversity natural habitat. The vital caveat would be that the adverse effects on biodiversity in cropped environments must be mitigated by specifically targeted conservation. The global implications of this conclusion, for organic farming, transgenic crops wildlife and trade require study. For example, Conway (1997) envisaged that it might be feasible to use some set-aside, for example in the USA specifically to export wheat to the developing world. How could such imports be paid for by the developing world? How could dumping be avoided? Most important how could the environmental benefits in the developing world be 'factored-into' the transactions? Could there be a kind of "debt for nature swap" approach? In essence, who is to pay to manage biodiversity? Some of these issues seem more urgent than global warming.

We can have the extra food and save biodiversity, but it will not happen with the policies of the 20^{th} century.

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