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Biodiversity and Agricultural Biotechnology

A Review of the Impact of
Agricultural Biotechnology on Biodiversity

Executive Summary

This paper gives an overview of biodiversity and how it is impacted by agriculture, building upon chapters on the impact of biotechnology on biodiversity for the European Federation of Biotechnology (Braun & Bennett, 2001) and UNESCO (Braun & Ammann, 2002). Biodiversity encompasses the fundamental bases of life on earth, including genetic, species and ecosystem diversity. There is a need to better understand biodiversity in terms of its fundamental components (genes and taxa), the interrelatedness of these components (ecology), their importance for human life and life in general, and the factors that threaten biodiversity. Biodiversity is concentrated in unmanaged habitats within the tropics. In temperate zones, particularly in the European Union, almost 50% of the landscape is agricultural, and agricultural lands contain a significant portion of the biodiversity in these zones. The greatest threats to biodiversity are destruction and deterioration of habitats, particularly in tropical developing countries, and introductions of exotic species. Maintaining biodiversity requires addressing these threats.

Many of the factors affecting biodiversity are related directly or indirectly to the needs of agricultural production, and it is important to consider how these impacts could be mitigated. Increasing human population and limited arable land have demanded increased agricultural productivity leading to more intensive agricultural practices on a global basis. In response, higher yielding crop varieties have been coupled with increased inputs in the form of fertilizers and pesticides and more intensive practices such as greater tillage of soil. More recently, technological advances have led to the development of genetically modified (GM) crops with insect resistance and herbicide tolerance that have a demonstrated potential to enhance productivity. These technologies have been broadly adopted, replacing broad-spectrum insecticides in some systems and facilitating reductions in tillage in others.

Agricultural impacts on biodiversity can be divided into impacts on in-field biodiversity and impacts on natural (off-site) biodiversity. Intensive agriculture has negative impacts on both species and genetic biodiversity within agricultural systems, primarily because of low crop and structural diversity but also through pesticide use and tillage. These impacts can be addressed by encouraging diversification of agricultural systems, and by reducing broad-spectrum insecticide and tillage, both of which GM crops can achieve in some systems. Agricultural impacts on natural biodiversity primarily stem from conversion of natural habitats into agricultural production. Transport of fertilizers and pesticides into aquatic systems also cause significant habitat deterioration through eutrophication. Increasing the efficiency of agricultural production can reduce these impacts, as can minimizing off-site movement of fertilizers and pesticides by reducing tillage and total agricultural inputs. Technologies such as GM crops are important in this respect.

Overall, creating agricultural systems with minimal impact on biodiversity will require utilizing all available technologies while simultaneously encouraging appropriate farmer practices.

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Basics of Biodiversity

Definition of Biodiversity

Biological diversity is an imprecise term that may refer to diversity in a gene, species, community of species, or ecosystem. It is often contracted to *biodiversity* and used broadly with reference to the total biological diversity in an area or the earth as a whole. Biodiversity comprises all living beings, from the most primitive forms of viruses to the most sophisticated and highly evolved animals and plants. According to the Convention on Biological Diversity, biodiversity means “the variability among living organisms from all sources including, *inter alia*, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part” (CBD, 1992).

There are many websites dealing with biodiversity and its definition, amongst which:

- BioCase, A Biological Collection Access Service for Europe (BioCase, 2003),
- Natural Science Collections Alliance (Alliance, 2003),
- European Community Biodiversity Clearing House Mechanism (European Community, 2003)
- Euro+Med Plant Base (Euro+Med, 2003) with an European perspective.

The present section will look at biodiversity at all levels but the paper will then focus on gene and species diversity, particularly in terrestrial and freshwater environments.

Genetic, Species and Ecosystem Diversity

Genetic diversity

Genes are the basic building blocks of life. In many instances genetic sequences, functions and the proteins encoded by the genes are highly conserved across all species. The importance of genetic diversity is noted in the combination of genes within an organism (the genome), the variability in phenotype that they produce as well as their resilience and survival under selection. As such, it is widely believed that ecosystems, natural ecosystems in particular, should be managed in a way that protects the untapped resource of genes within their host organisms. Today, much work remains to be done to

both characterize genetic diversity and understand how best to protect and make wise use of it. (Raikhel & Minorsky, 2001).

Species diversity

For most practical purposes, species are the most appropriate targets for biodiversity research and species diversity is the most useful measure of biodiversity. There is no single definition of what a species is and species-level taxonomy can change with new data as well as new approaches. Nevertheless, a species could broadly be defined as a collection of populations that differ genetically from one another to a greater or lesser degree. These genetic differences manifest themselves as differences in morphology, physiology, behaviour and life histories; in other words, genetic characteristics affect expressed characteristics (phenotype). Today, about 1.75 million species have been described and named but the majority remains unknown. The global total might be ten times greater, many of these being undescribed insects (Table 1).

Table 1: Estimated numbers of described species and possible global total

Kingdoms	Phyla	Described species	Estimated total
Bacteria		4,000	1,000,000
Protoctista		80,000	600,000
Animalia			
	Craniata (vertebrates) total	52,000	55,000
	Mammals	4,630	
	Birds	9,946	
	Reptiles	7,400	
	Amphibians	4,950	
	Fishes	25,000	
	Mandibulata (insects & myriapods)	963,000	8,000,000
	Chelicerata (arachnids etc)	75,000	750,000
	Mollusca	70,000	200,000
	Crustacea	40,000	150,000
	Nematoda	25,000	400,000
Fungi		72,000	1,500,000
Plantae		270,000	320,000
TOTAL		1,750,000	14,000,000

(Source: World Conservation Monitoring Center 2000) (Groombridge & Jenkins, 2000)

Ecosystem diversity

At its highest level of organization, biodiversity is characterized as ecosystem diversity, which can be classified in the following three categories:

- Natural ecosystems, i.e. ecosystems free of anthropogenic management activities. These are composed of what has been broadly defined as “Native Biodiversity”. It is a matter of debate whether any

truly natural ecosystem exists today since man has influenced with its activity most regions on earth.

- Semi-natural ecosystems, in which human activity is limited. These are important ecosystems that are subject to some level of low intensity human disturbance. These areas typically abut managed ecosystems.
- The third broad classification of ecosystems is “managed”. Such system can be managed to varying degrees of intensity from the most intensive, conventional agriculture and urbanized areas, to less intensive systems including some forms of agriculture in emerging economies.

Beyond simple models of how ecosystems appear to operate, we remain largely ignorant of how they function, how different ecosystems might interact with each other, and which ecosystems are critical to the services most vital to life on Earth. The role of the forests for water management is crucial in all forested habitats, from the temperate to the tropical rainforests, and due to acute threats through urbanisation, in particular also the dry tropical forests. Because we know so little about the ecosystems that provide our life-support, we should be cautious and work to preserve the broadest possible range of ecosystems.

Let's sum up with the words of Lyn Margulis:

"What is life? is a linguistic trap. To answer according to the rules of grammar, we must supply a noun, a thing. But life on Earth is more like a verb. It is a material process, surfing over matter like a strange slow wave. It is a controlled artistic chaos, a set of chemical reactions so staggeringly complex that more than 4 billion years ago it began a sojourn that now, in human form, composes love letters and uses silicon computers to calculate the temperature of matter at the birth of the universe." (Margulis, 1995)

Distribution of Biodiversity

Biodiversity is not distributed evenly over the planet. Species richness is highest in warmer, wetter, topographically varied, less seasonal and lower elevation areas. There are far more species in total per unit area in temperate regions than in polar ones, and far more again in the tropics than in temperate regions (Figure 1). Latin America, the Caribbean, Asia and the Pacific host together 80% of the ecological megadiversity of the world.

Within each region, every specific type of ecosystem will support its own unique suite of species, with their diverse genotypes and phenotypes. In numerical terms, global species diversity is concentrated in tropical rain forests. The Amazon basin contains for example 87 to nearly 300 different tree species per hectare and supports the richest fish fauna known, with more

than 2500 species. The forests in Asia and South America are considered to be especially rich in animal species.

Species and genetic diversity within any agricultural field will be more limited than in a natural or semi-natural ecosystem. Nevertheless, agricultural ecosystem can be dynamic in terms of species diversity over time due to the amount of management. Biodiversity in agricultural settings is extremely important at country level in areas where the proportion of land allocated to agriculture is high. This is the case in Europe for example, where 45% of the land is dedicated to arable and permanent crop or permanent pasture (FAOSTAT, 2003). In the UK, this figure is even higher, at 70%.

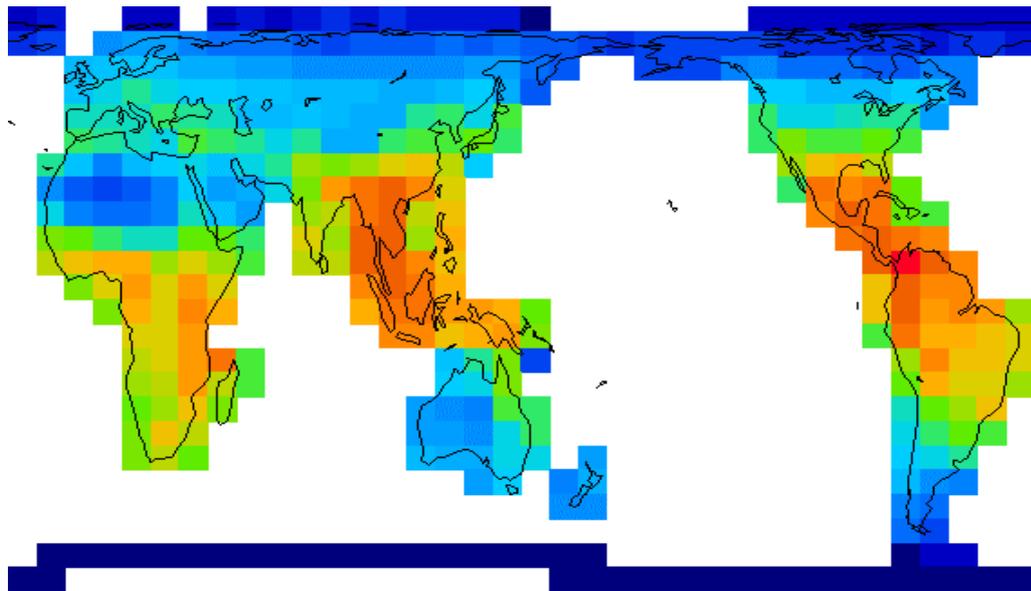


Figure 1: Global biodiversity value: a map showing the distribution of some of the most highly valued terrestrial biodiversity world-wide (mammals, reptiles, amphibians and seed plants), using family-level data for equal-area grid cells, with red for high biodiversity and blue for low biodiversity (Williams, 2003)

Loss of Biodiversity

Threats to global biodiversity

Loss of biodiversity is occurring in many parts of the globe, often at a rapid pace. It can be measured by loss of individual species, groups of species or decreases in numbers of individual organisms. In a given location, the loss will often reflect the degradation or destruction of a whole ecosystem. Recently the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA, 2003) of the Convention on Biological Diversity ranked threats to global biodiversity in the following manner:

- Habitat loss
- Introduction of exotic species

- o Further: flooding, lack of water, climate changes, salination etc., all of which may be either natural or man-made (not dealt with in this report).

The United Nations Environment Program, in their 1997 Global State of the Environment report (UNEP, 1997), described regional environmental trends as shown in Figure 2.

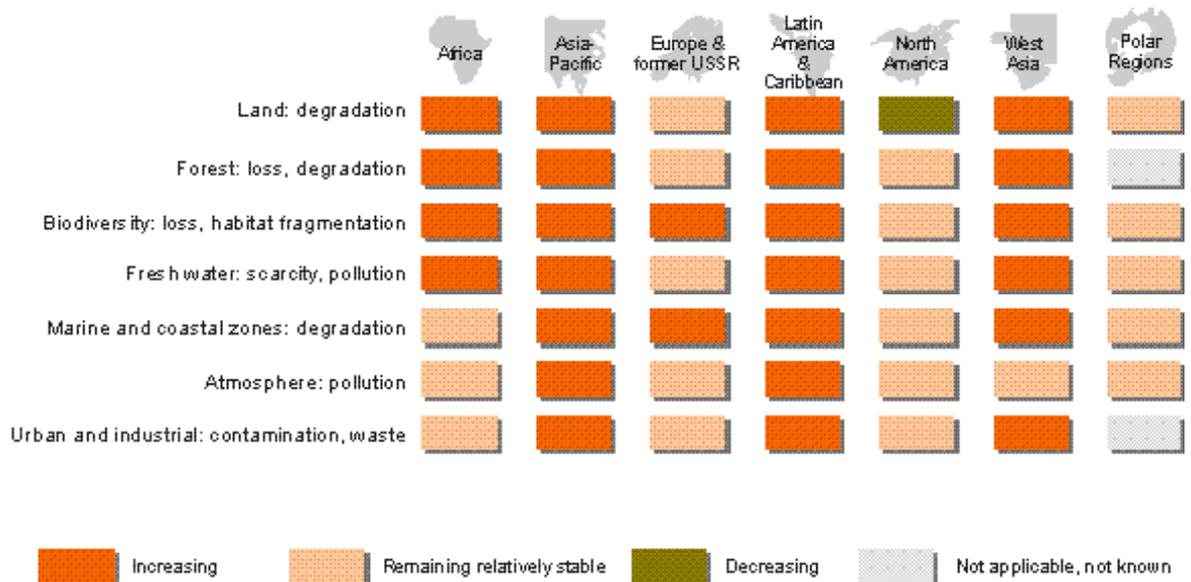


Figure 2: Regional environmental trends in habitat loss (UNEP, 1997).

The unchecked exponential growth of human population has had dramatic effects on biodiversity worldwide. Habitat loss due to the expansion of human activities is identified as a main threat to 85% of all species described in the IUCN Red List. Main factors are urbanisation and the increase in cultivated land surfaces.

Today, more than half of humankind lives in urban areas, a figure predicted to increase to 60% by 2020 when Europe, Latin America and North America will have more than 80% of their population living in urban zones. Five thousand years ago, the amount of agricultural land in the world is believed to have been negligible. In 2000, arable and permanent cropland covered approximately 1,497 million hectares of land, with some 3,477 million hectares of additional land classed as permanent pasture (Figure 3). The sum represents approximately 38% of total available land surface (13,062 million ha, according to (FAOSTAT, 2003).

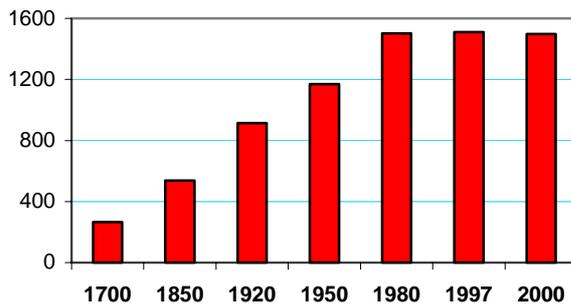


Figure 3: Land converted to arable and permanent cropland, in million hectares (FAOSTAT, 2003)

Habitat loss is of particular importance in regions of high biological diversity where at the same time food security and poverty alleviation are key priorities (e.g. some parts of Latin America and Asia Pacific for example). Forests are a good example: the impacts of development activities and the advance of the agricultural frontier has led to an overall decline in the world's forests and woodlands of approximately 2% between 1980 and 1990. While the area of forest in industrialised regions remained fairly unchanged, natural forest cover declined by 8% in developing regions (UNEP, 1997)

Introduction of exotic species

Unplanned or poorly planned introduction of non-native species and genetic stocks is a major threat to terrestrial and aquatic biodiversity worldwide. According to (Sukopp & Sukopp, 1993) there are hundreds if not thousands of new and foreign genomes introduced with trees, shrubs, herbs, microbes and higher and lower animals each year. Many of those survive and can, after years and even many decades of adaptation, begin to be invasive.

Terrestrial areas most affected by the introduction of exotic species include forests, Mediterranean regions as well as similar types of natural vegetation in the Cape Province of South Africa, parts of Chile, Southern Australia and California, grasslands and savannas and agricultural lands. One of the most extreme examples is seen in the pampas of Argentina, a flat grassland with a moderate climate, from which nearly all the native grasses have disappeared and have been replaced by European plants. Islands and other areas having evolved unique ecosystems are particularly at risk (CBD-ALIEN).

Freshwater habitats worldwide are amongst the most modified by humans, especially in temperate regions. In most areas, introduction of non-native species is the most or second most important activity affecting inland aquatic areas, with significant and often irreversible impacts on biodiversity and ecosystem function. A classic example is the extinction of half to two thirds of the haplochromine cichlid fish population in Lake Victoria after the introduction of the Nile perch *Lates niloticus*, a top predator. Also, several species of free-

floating aquatic plants able to spread by vegetative growth have dispersed widely over the globe and become major pests, as a notable example in the Northern Hemisphere *Elodea canadensis*, Elodea, Common Waterweed.

Loss of biodiversity in the agricultural environment

In an agricultural context, a rapid decline in species and genetic diversity has been brought about by the success of new commercial varieties. Reported losses of over 80% of varieties in species such as apple, maize, tomato, wheat and cabbage have occurred worldwide (UNEP World Conservation Monitoring Centre, 2003). Studies in population genetics raised concern over genetic erosion and the recognition of the importance of plant genetic material in the development of new varieties led to the establishment in the 1970's of the International Plant Genetic Resources Institute (FAO, 2003; IPGRI, 2003) and increased efforts to collect germplasm for *ex-situ* collections.

Terrestrial but also aquatic biodiversity within and around agricultural fields, as discussed in Chapter 3, has also been strongly influenced by agricultural practices. Fertilisers, pest control chemicals, tillage and even crop rotation have been shown to profoundly impact the richness and diversity of agricultural ecosystems.

Importance of Biodiversity

Biological diversity has emerged in the past decade as a key area of concern for sustainable development. It provides a source of significant economic, aesthetic, health and cultural benefits. The well-being and prosperity of earth's ecological balance as well as human society directly depend on the extent and status of biological diversity.

Biodiversity plays a crucial role in all the major biogeochemical cycles of the planet. Plant and animal diversity ensure a constant and varied source of food, medicine and raw material of all sorts for human populations. In agriculture, biodiversity represents a critical source of genetic material allowing the development of new and improved crop varieties. In addition to these direct-use benefits, there are enormous other less tangible benefits to be derived from natural ecosystems and their components. These include the values attached to the persistence, locally or globally, of natural landscapes and wildlife, values, which increase as such landscapes and wildlife become scarcer.

Ever since the first Stockholm Report of the United Nations Environmental Programme (UNEP, 1972), biodiversity has been indirectly on the global agenda. In view of the importance of biodiversity for the future of mankind, several international agreements aiming at relieving some of the pressure on selected important resources have been reached. These include for example the numerous regional fishery management schemes, the Convention on International Trade in Endangered Species (CITES), and more recently the Convention on Biological Diversity (CBD, 1992)..

Convention of Biological Diversity (CBD)

The CBD was negotiated under the auspices of the United Nations Environment Programme (UNEP) and entered into force on 29 December 1993. The convention has three goals: promote the conservation of biodiversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising out of the utilization of genetic resources.

A radical change brought about by the CBD is the recognition that States have a sovereign right over biodiversity within their own territory: previously organisms were considered to be the common heritage of mankind. Living organisms or their products may, under the terms of the CBD, only be removed from a country under mutually agreed conditions.

The CBD is a comprehensive approach to biodiversity conservation of both wild and domesticated species. It aims at conservation at the genetic, species and ecosystem levels. As reviewed by (Buhenne-Guilmin & L., 1994), action is delegated to the national level obliging States to assess biodiversity, enact legislation for its conservation *in situ* and *ex situ*, and to enforce legislation within national boundaries.

Section 2

Agricultural Practices

A number of tools are currently in use to produce sufficient food for the world. World food production almost doubled in the thirty-five years from 1961-1996 (FAOSTAT, 2003); (Tilman, 1999). This was accomplished with only a 1.1 fold increase in cultivated lands and was made possible due to dramatic changes in agricultural practices including use of fertilisers and pest control compounds, implementation of specific agricultural practices, shifts to higher yielding varieties and adoption of new technologies. The following section will review current common agricultural practices that are used to increase productivity.

Agricultural inputs

The productivity of crop plants is challenged by abiotic and biotic stresses. Abiotic stresses include nutrient deficiencies, water challenges as well as soil acidity, alkalinity and salinity. Fertilization and irrigation are two important tools for addressing these problems. Nitrogen and phosphorous fertilizers are commonly applied. In fact, the doubling in world food production cited above was accompanied by a 6.87 fold increase in nitrogen fertilization and a 3.48 fold increase in phosphorous fertilization. In that same time, water challenges were met by increasing irrigated lands by 1.68 fold (FAOSTAT, 2003; Tilman, 1999).

Biotic stresses include weeds, insects and plant pathogens such as fungi, viruses and bacteria. A number of pesticides are commonly used to control these pests. Nevertheless, between 35-42% of the world's food and fibre is lost from damage by pests despite the use of 2.5 million metric tons of pesticides (Oerke, 1994; Oerke & Dehne, 1997; Pimentel, 2001);. Weeds cause 10-13% loss, insects 13-16% and pathogens 12-13%. Without pesticides or other pest control measures, it has been estimated that the losses would increase to 70% with an economic loss of \$400 billion USD per year (Oerke & Dehne, 1997). Pest control measures are a positive economic investment for farmers yielding a return of \$3-4 USD for each dollar invested (Pimentel & Lehman, 1993).

Weeds are a major problem in many crops so herbicides are an important tools in these crops. Over 90% of US soybean acres and 70% of Brazilian and Argentine soybean acres are treated with herbicides (Oerke & Dehne, 1997). For maize, over 95% of US acres are treated with herbicides (USDA-NASS, 2002). Herbicide tolerant crops can provide an opportunity to reduce herbicides in such systems. In the US, an average 10% reduction in herbicide

usage was seen with herbicide tolerant soya from 1995-1998 (Hin et al., 2001). A more recent study found a reduction of 28.7 million pounds of active ingredient in herbicide tolerant soya in the US in 2001 (Carpenter, 2001). In the EU, a standard maize herbicide program uses approximately 1740 g of active ingredient per hectare but this amount could be reduced by 30-60% if GM technology were adopted (Phipps & Park, 2002). Similar levels of herbicide reductions were projected for winter oil seed rape (for UK) and sugar beet (for Denmark) if GM crops with herbicide tolerance were adopted in these countries (Phipps & Park, 2002).

Control of other pests is critical in a number of crops. High levels of insecticide are used to control ravaging insects in many of the world's cotton growing areas for example, reducing crop losses in some regions from 35 – 39% to 13% or less (Oerke, 2002) , (James, 2002). Adoption of insect protected cotton has impacted the level of insecticides used this crop in many areas (James, 2002). In the US, the estimated savings in metric tons (MT) of active ingredient are 848 in 2001 (Gianessi et al., 2002), 1224 MT in 1999 and 907 MT in 1998 (Carpenter, 2001). In China, an 80% reduction in kg of formulated product used was seen due to the adoption of GM cotton (Huang et al., 2002). Introducing GM cotton in Spain would lead to a 60% reduction in volume of pesticide used and nearly a 40% reduction in active ingredient used (Phipps & Park, 2002).

Cultural Practices

Crop rotation

Crop rotation is a very common practice as a means of controlling pests. Since some pest species rely on specific crops as hosts, then rotating to another crop can reduce populations of such pests. Crop rotation has been applied in virtually all agricultural strategies, from classic and historic agriculture such as the one still in place in certain actively protected localities in the Swiss Valais (Waldis, 1987). The maize/soybean rotation in the United States as a means of controlling corn rootworm is one example of such a rotation designed to aid in pest control efforts. Another example is that of glyphosate-tolerant Roundup Ready® soybeans which are often rotated with such crops as corn, winter wheat, spring cereals and dry beans (OECD, 2000). An interesting study from Canada shows enhancement of some agricultural parameters after 8 years in the second rotation cycle: N fertilizer requirement decreased, and wheat yield was 22% higher, under no tillage conditions as compared to conventional tillage. (Soon & Clayton, 2002). A comprehensive insight is delivered by the (FAO, 2003).

Tillage

The soil in a given geographical area has played an important role in determining agricultural practices since the time of the origin of agriculture in the Fertile Crescent of the Middle East. Soil is a precious and finite resource. Soil composition, texture, nutrient levels, acidity, alkalinity and salinity are all

determinants of productivity. Agricultural practices can lead to soil degradation and the loss in the ability of a soil to produce crops. Examples of soil degradation include erosion, salinization, nutrient loss and biological deterioration. It has been estimated that 67% of the world's agricultural soils have been degraded (World Resources, 2000).

At one time, tillage of soil was an essential tool for the control of weeds. Unfortunately, tillage practices can lead to soil degradation by causing erosion, reducing soil quality and harming biological diversity. Tillage systems can be classified according to how much crop residue is left on the soil surface (Fawcett et al., 1994; Fawcett & Towery, 2002; Trevavas, 2001). Conservation tillage is defined as "any tillage and planting system that covers more than 30% of the soil surface with crop residue, after planting, to reduce soil erosion by water" (Fawcett & Towery, 2002). The value of reducing tillage was long recognized but the level of weed control a farmer required was viewed as a deterrent for adopting conservation tillage. Once effective herbicides were introduced in the latter half of the 20th century, farmers were able to reduce their dependence on tillage. The development of crop varieties tolerant to herbicides has provided new tools and practices for controlling weeds and has accelerated the adoption of conservation tillage practices (Fawcett & Towery, 2002). Herbicide tolerant cotton has been rapidly adopted since its introduction in (Fawcett et al., 1994). In the US, 80% of growers are making fewer tillage passes and 75% are leaving more crop residue (Cotton Council, 2003). In a farmer survey, seventy-one percent of the growers responded that herbicide tolerant cotton had the greatest impact on toward the adoption of reduced tillage or no-till practices (Cotton Council, 2003). In soybean, the growers of glyphosate tolerant soybean plant higher percentage of their acreage using no-till or reduced tillage practices than growers of conventional soybeans (American Soybean Association, 2001). Fifty-eight percent of glyphosate-tolerant soybean adopters reported making fewer tillage passes versus five years ago compared to only 20% of non-glyphosate tolerant soybean users (American Soybean Association, 2001). Fifty four percent of growers cited the introduction of glyphosate tolerant soybeans as the factor which had the greatest impact toward the adoption of reduced tillage or no-till (American Soybean Association, 2001)

Germplasm

Crops and varieties

In agriculture, 7'000 species of plants are used by farmers somewhere in the world, but only 30 species provide 90 percent of our calorific intake (Heywood, 2003). The top three crops are wheat, rice and maize (corn) occupying 230 million hectares, 151 million hectares and 140 million hectares, respectively, which is 35% of all global cropland. Each of the three major crops originated in different regions of the world. Wheat originated in the Near East, rice in both eastern Asia and western Africa and maize in the Americas. Within these dominant crop species, there are many hundred thousands of varieties

(landraces, cultivars) adapted to local climates, farming practices, and cultural predilections like taste, color, structure, ability to store the products etc. Much of this large crop diversity is important for providing the initial material for breeding. However, it must be recalled that the genetic diversity found in crops is much less broad than the genetic diversity observed in plants or animals living in the wild, which points to the importance of wild species for agricultural breeding programs.

A major factor in the doubling of food production was the introduction of improved varieties (See (Pfeiffer, 2003) for review of breeding improvements in the Green Revolution, a brief discussion of which follows). For both rice and wheat, these repeated crossings led to varieties with four important characteristics: (1) higher yield; (2) fast maturation; (3) semidwarf growth habit and (4) resistance to disease. Once these characteristics were introduced, crossings to local varieties produced crops that are regionally adapted for optimized growth and consumer desires. The improved varieties were not just new seeds, but required the adoption of a suite of new agricultural tools. These tools included inputs such as fertilizers and pesticides, equipment for irrigation and tillage. The new technology package was important to optimize the output of the new varieties and thus realize the tremendous gains in productivity seen with the Green Revolution.

Evolution of plant breeding

For most major crops, breeder's collections are sufficiently large to provide an adequate source of additional genetic material. Material from landraces and con-specific wild populations (primary gene pools) are also frequently called upon. FAO have estimated that 30 – 40% of productivity gains overall have relied on genetic contributions from landraces. The secondary gene pool, consisting of related species in the wild or in cultivation, has also provided important and economically valuable contributions to major crops. However, the difficulty of crossing different species using conventional methods has until now limited the use of this genetic resource. Gene transfer technology has the potential to avoid some of the difficulties limiting conventional techniques and brings the possibility of introducing into cultivars traits from an unlimited gene pool. Such processes could perhaps provide new economic incentives to conserve agricultural biodiversity.

Genetically modified (GM) crops are only the last development stage in a long row of breeding method enhancements, and certainly the list will be longer with the years to come. If one looks closer at the development of modern breeding methods, 13 steps can be discerned before reaching true transformation through genetic engineering, as described in the box below:

13 Steps in plant breeding from mass selection to genetic engineering, after (Karutz, 1999)

1. Selection of characteristic, homogenous varieties from traditional local or indigenous origin (e.g. land races) that generally exhibit more or less variable populations, by testing the offspring.

2. Crossing of homogenous varieties to create new variability followed by subsequent selection.
3. Intentional introduction by crossing in of desired traits for instance resistances. (Even if 'genes' such as 'mlo' or 'Lr 27' are in question the manipulations are carried out with pollen and ears of grain - not with DNA).
4. Artificial infection of plants in greenhouse or field by means of contact with neighbouring infected plants or a concentrated liquid spray of fungal spores. This is done to select for resistance. (On account of the high cost this is not widely practised).
5. Intentional use of the heterosis effect in hybrid breeding. (This often requires preparatory steps: some years of inbreeding if cross-pollinated species are involved, or in the case of self-pollinated species, the artificial production of male sterility – cytoplasmic, chemical or by genetic engineering.)
6. Crossing to introduce characters from more distantly related species. (This often necessitates the cultivation of the crossed embryos in a nutritive medium, since embryos left in the seeds would die owing to incompatibility. This is called 'embryo rescue' (Becker, 1993).
7. Colchicising (treating with the toxin of the autumn crocus, *Colchicum autumnale*), to double the number of chromosomes). In many vegetable and fodder crops this enables a stronger expression of certain traits such as frost resistance. It also permits the crossing of two different species or even families, because it can render fertile the sterile offspring of crosses. The most well known example in practice is Triticale, a new species of grain, the result of crossing wheat (*Triticum*) and rye (*Secale*), two different families. (Bayerische Landesanstalt & für Landwirtschaft (LfL), 2003), (Schmid, 1985)
8. Inducing mutations with chemicals or ionising radiations and subsequent selection. This method enjoyed a certain boom 10 to 20 years ago but is not much used nowadays since the mutations are mostly disadvantageous. There exist however, short-strawed strains of wheat that were obtained in this way (Fossati et al., 1986), and see (FAO/IAEA Programme, 2003), where you will discover 548 seed propagated crops which have undergone gamma mutation programmes, some of them undoubtedly have also been introduced in later breeding programmes of all kinds.
9. Anther culture. In this way it is possible, in the case of self-fertile heterozygotes whose progeny in the next generation would otherwise diversify, to 'freeze up' so to speak the haploid chromosome set of the pollen or the ovule. The pollen or the unfertilised ovule must be placed on a special sterile nutrient medium, fused by treating with colchicine and raised to become haploid plants, followed by subsequent colchicising. Thus with one stroke one obtains a homogenous plant which would otherwise only be achieved by many generations of selection. Anther culture is established mostly in barley and potatoes. With wheat and maize it is still at the experimental stage. (Bayerische Landesanstalt & für Landwirtschaft (LfL), 2003)
10. In-vitro-selection. If seedlings or tissue fragments can be selected in culture dishes for resistance against a fungal toxin, the cost of field trials is less because many plants will be discarded from the outset. For many traits, such methods are very successful and great efforts are being made to introduce them into routine breeding. Selection for traits: (Safamejad et al., 1996), selection for proteins: (Hanes & Pluckthun, 1997)
11. Somatic hybridising (i.e. non-sexual fusion of two somatic cells). The advantage of this method is that by the fusion of cells with different numbers of chromosomes (for instance different species of *Solanum*²⁴) fertile products of the crossing are obtained at once because diploid cells are being somatically fused. Polyploid plants are obtained containing all the chromosomes of both parents instead of the usual half set of chromosomes from each. For this, cells are required whose cell walls have been digested away by means of enzymes and are only enclosed by a membrane, (these are then called protoplasts). With the loss of their cell walls, protoplasts have also lost their typical shape and are spherical like egg cells. This mixture of cells to be fused is then exposed to electric pulses. In order to get from the cell mixture the 'right' product of the fusion (since fusion of two cells from similar plants can also occur) one different selectable character in each of the original plants is necessary. Only cells that survive this double selection are genuine products of fusion. (The easiest way to achieve such selectable markers is by genetic engineering, for instance by incorporating antibiotic resistance into the original plants.) Protoplast fusion has been investigated and applied to potatoes, for instance. In the EU regulations concerning the deliberate release of genetically modified organisms into the environment somatic hybrids are not considered as GMO's and do not require authorization.²⁵ The most

recent draft of the EU organic regulations in which the introduction of GMOs in organic cultivation is forbidden, follows the above definition. (Koop et al., 1996).

12. Marker-assisted selection. For the purpose of diagnosis, DNA from all the plants from which selection is to be made, is isolated and, with the help of enzymes, broken up into smaller or larger pieces. These, in a gel-like mass, are separated in an electric field (gel electrophoresis) according to their size. By various methods, individual pieces are made visible by radioactive or fluorescent markings. Then, on the gel under ultra-violet light, or on an X-ray film of the gel, a characteristic band pattern for every genotype can be seen. By means of the enzyme and DNA probe used and from their size (i.e. the number of their base pairs determined with the help of standards), these bands can be defined. Presently there are a number of modified methods, but the principle is the same. One looks out for bands that correlate statistically with the particular feature. Once such 'markers' have been found one has a simple criterion for selection. A fragment of leaf of the relevant plant furnishes sufficient DNA for such a diagnosis since the DNA can be artificially multiplied in the laboratory. Selection with the aid of markers is very extensively researched for every sort of cultivated plant and every conceivable trait. At the present time many breeders consider it to be *the* investment for the future that will bring about the greatest changes during the next decade. In the coming years it will be integrated into practically all the major breeding programmes. Above all, it will enormously accelerate the process of breeding. Selection will be automated and take place in the laboratory. It will be possible to reduce field trials drastically. For perennial plants it will be of particular interest as well as for projects where one wants to combine many dominantly inherited resistances to the same disease in one variety (pyramiding). Otherwise there is no means of knowing in such projects whether a further resistance exists if the first is already active. This might provide a contribution to permanent disease resistances. Also for complex traits inherited as polygenes the method would promise a speeding up of selection. This method certainly implies working with isolated DNA, but without invasion of the genome of the plant and is therefore not seriously disputed. One must be aware that much genetic engineering with bacteria was and is necessary to establish marker-assisted selection. (Stein et al., 2001)

13. Gene transfer. With gene transfer there are also many degrees of departure from the 'natural' according to the origin of the genes and the technology employed in the transfer. (de la Riva et al., 1998), (Potrykus, 1990)

Modern breeding will depend more and more on molecular methods, which will develop even faster in the years to come, its success will provoke renewed debates on the exclusion of such methods from certain breeding programmes as e.g. in organic farming (Ammann, 2000).

Genetically Modified (GM) Crops

Early history

Since all genes consist of DNA, and the information in this DNA molecule is read in the same way in all organisms in order to make proteins, it is in principle possible to take any (single) gene from any organism and transfer it into any other organism so that the recipient produces a protein normally only made in the donor. The resulting organism is called a Genetically Modified Organism (GMO).

From the time this simple strategy was devised (Cohen et al., 1973) and (Morrow et al., 1974), it took molecular biologists about a decade until the first GM plants were made in 1985. Ten years later, the first GM crop appeared in supermarkets in the USA, the "FlavrSavr" tomato with a delayed ripening process. The FDA's review of the Flavr Savr was requested by the tomato's developer, Calgene Inc. of Davis, California, in August, 1991. The company

later submitted a food additive petition on the use of the kan-r gene in the development of new varieties of tomato, cotton, and rapeseed. In 1990-92, the U.S. Department of Agriculture granted Calgene permission to begin large-scale production of the new tomato (FDA, 1990), final approval by fax May 1994. (Maryanski, 1999). Agronomic traits followed in 1996 with the introduction of herbicide tolerant soybean and insect-resistant cotton.

Global adoption

The adoption of GM crops is, in a worldwide view, a success story without precedent. (James, 2002) compiled information on adoption rates globally. In 2002, four countries grew 99% of the global transgenic crop area. The USA led the world with 39.0 million hectares (66% of global total) Argentina followed with 13.5 million hectares (23%), Canada 3.5 million hectares (6%) and China 2.1 million hectares (4%). China showed the greatest growth with a 40% increase in its insect resistant cotton area from 1.5 million hectares in 2001 to 2.1 million hectares in 2002. This represents 51% of the total cotton area of 4.1 million hectares in China. Argentina increased its GM crop area by 14% from 11.8 million hectares in 2001 to 13.5 million hectares in 2002. South Africa increased its growings by 20% to 0.3 million hectares in 2002. The US and Canada both showed a growth rate of 9%. GM cotton area in Australia decreased by half in 2002, due to the very severe drought conditions. India, Colombia and Honduras grew transgenic crops for the first time in 2002. Overall, The number of countries that grew GM crops increased from 13 to 16 in 2002 – 9 developing countries, 5 industrial and 2 Eastern Europe countries (James, 2002).

Current products

(James, 2002) also tracked the type of crops being grown globally. In 2002, the principal GM crops were: soybean occupying 36.5 million hectares (with 51% of all soybean transgenic), cotton at 6.8 million hectares (12% of all cotton was GM); canola at 3.0 million hectares (12% of canola now GM) and maize at 12.4 million hectares (9% of maize now GM). Herbicide tolerance has consistently been the dominant trait followed by insect resistance. In 2002, herbicide tolerance was deployed in soybean, corn, cotton and canola and occupied 75% or 44.2 million hectares of the global 58.7 million hectares. Herbicide tolerant soybean was the single biggest trait/crop with 36.5 million hectares. Insect protected crops were offered in maize and cotton and covered 10.1 million hectares of the global transgenic area in 2002. Bt maize covered 7.7 million of those hectares. Stacked gene combinations with both herbicide tolerance and insect protected traits in the same product were offered in both cotton and maize and occupied 4.4 million hectares in 2002. A small amount of GM crops with virus resistance was also grown in 2002.

Future products

In the future, it is expected that there will be many more categories than just crops with herbicide and pest-tolerance, viral and drought resistance. Future crops will offer additional benefits, for example improved nutrition and quality

traits or improved food production efficiency. Crops will be designed to produce valuable pharmaceutical ingredients and renewable energy. It is not easy to predict trends, but through the study of ongoing projects some research tendencies can be understood. A large number of GM crops with enhanced nutritional values are in the development stage and will only come into market in a few years from now (Bouis, 1996; Vonbraun et al., 1990). They are likely to show benefits for the consumers and some may be of particular interest to farmers in tropical countries. Sooner or later regulators must learn, especially in Europe, to shift from process-oriented to trait-oriented legislation (Miller, 2002).

One of the most popular traits which will offer fortified rice meals is known as the Golden Rice (Potrykus, 2001). Two rice varieties, with anticipated consumer benefits, are those containing Pro-Vitamin A or an increased level of iron in the product, which were developed by Potrykus and Beyer (Beyer et al., 2002), starting with (Peterhans, 1990). Despite traditional preventive measures (distribution of free vitamin A, encouragement to eat more fruit and vegetables), worldwide there are 130 million young people who are vitamin A-deficient, An estimated 250'000 to 500'000 vitamin A-deficient children become blind every year, half of them dying within 12 months of losing their sight. (WHO, 2002). A bowl of 200-300 g of this cooked rice is according to latest data enough to overcome the vitamin A-deficiency to a significant degree. Similarly iron-deficiency, particularly prevalent in pregnant women, can potentially be alleviated by rice containing an increased amount of iron in its endosperm. Such rice varieties have been successfully developed in the laboratory. In the last two years the lab plants have been completely redesigned for field use, first field trials are under way at the , but are still a few years from commercialization, for both scientific and political reasons. (King, 2002a). It is anyway economically highly beneficial to develop fortified crop varieties instead of going on with expensive and inefficient international food aid, high priority has to be assigned (among many other points) to research in modern plant breeding (Pinstrup-Andersen, 2002; Pinstrup-Andersen & Cohen, 2003). There are many other research projects on fortified food going on: Cassava, potatoe, maize, beans etc. (Welch, 2002), (King, 2002a; King, 2002b).

Biotechnology and plant breeding

Biotechnology is a valuable tool in plant breeding from 2 different aspects: as a tool to transfer new genes into crop varieties and introduce desired characteristics (as discussed previously), or as a tool for acquiring knowledge.

Today, biological research can hardly be conducted without using biotechnology in one way or another. Taxonomy and conservation use molecular markers to identify species, much in the same way as in forensic medicine to identify criminals. This is useful for *ex situ* and *in situ* conservation of plants. In seedbanks and conservation projects, genetic fingerprints are used to establish the origin of a seed or the relatedness of one plant variety to another. There are many texts on the use of molecular biology methods in

conservation, (Jacobsen & Dohmen, 1990), (Fay, 1992), (Drilling, 2003), (Students, 1999), (Frankham, 2003), (Lledó et al., 1996).

Biotechnology also is used for important phylogenetical studies in plant systematics, the application of various methods has led to breakthroughs in systematic botany: Results of the application of modern biological and statistical methods can be seen in (Stevens, 2003), an website on phylogenetic trees of the flowering plants, and a textbook: (Hollingsworth et al., 1999). It is even possible to use the invaluable collections of herbarium plants in pressed and dried condition as a good source for DNA studies (Missouri, 2003). Molecular data are surprisingly well matching the non-molecular ones, as has been shown by a thorough analysis (Bremer, 1998), (Nandi, 1998).

Biotechnology has proven useful for following genetic markers in plant breeding. Here, plant varieties are crossed by conventional means. By analysing a few cells of the newly sprouted plant, one can predict some of the expected properties of the progeny, by looking at the presence or absence of certain genes. This enables one to predict a phenotypic property, which will only show up later in life, for instance the crop's expected resistance to an infectious plant disease.

These applications of biotechnology are in general not controversial. Here, the public perception is similar to the application of modern biotechnology in medicine, for instance to industrially produced pharmaceuticals, vaccines and diagnostics. It may be noted that the worldwide sales of biotechnology products in 1999 was worth around 13 billion dollars in the medical field and only 1.6 billion in agriculture.

The availability of genome sequences will be a boost to research. The first two complete plant genome sequences determined were those of *Arabidopsis* and rice. The 120 million base pairs (MBP) of the small brassica *Arabidopsis* were sequenced by an international academic consortium and the data made public. The 430 MBP sequence of rice was completed only a few weeks later by an industrial group lead by Syngenta, and will be available by contract to other researchers. Syngenta intends to make the data available free of charge for research directly benefiting subsistence farmers. The public sector sequencing of rice through an international consortium is expected to be completed in 2004. It will hopefully become common practice for companies to make their basic discoveries publicly available, to everyone's benefit. The Monsanto company has also opened up some of its rice sequencing data. An easy way to follow up the progress is to check the Genomics Gateway of (Nature, 2003 ff).

Section 3

The Impacts of Agricultural Practices on Biodiversity

The following section discusses the impacts of common agricultural practices on biodiversity, and ways in which some of these impacts can be mitigated. As presented in Section 1, biodiversity can be quantified in several different, equally important ways, thus agricultural impacts on biodiversity are considered both in terms of species and genetic diversity. Within each of these categories, the impacts on agricultural biodiversity and natural biodiversity are addressed separately because the impacts of agriculture are different on these two types of habitat. This distinction could also be thought of as on-site and off-site impacts of agricultural practices.

Impacts on Species Biodiversity

Agricultural biodiversity

General impacts of modern intensive agriculture

Modern agricultural practices have been broadly linked to declines in biodiversity in agro-ecosystems. This has been found to be true for a wide variety of taxonomic groups, geographic regions and spatial scales. More specifically, various researchers have found significant correlations between reductions in biodiversity at various taxonomic levels and measures of agricultural intensification. For example, a review of published studies on arthropod diversity in agricultural landscapes found species biodiversity to be higher in less intensely cultivated habitats (Duelli et al., 1999). Similarly, analysis of 30 years of monitoring records demonstrated that the abundance of aerial invertebrates at a location in rural Scotland was negatively correlated with a suite of agricultural variables that represent more intensive agriculture; that is, arthropod populations are lowest where agriculture is the most intensive (Benton et al., 2002). In this same study, the abundance of various farmland bird species was, in turn, positively correlated with arthropod abundance in the same year and the previous year. Comparable studies have found similar impacts on bird species throughout the United Kingdom and European Union (EU). Across Europe, declines in farmland bird diversity are correlated with agricultural intensity and declines in the European Union have been greater than in non-Member States (for example, see (Donald et al., 2002a; Donald et al., 2002b).

These effects of agricultural intensification undoubtedly reflect a large number of factors which are addressed individually in the following sections, including the cropping pattern, the frequency of tillage, the amount and nature of fertilizers used, and the amount and nature of pesticides applied (particularly insecticides and herbicides). However, it should be kept in mind that all of these factors are interrelated to a greater or lesser degree.

Crop diversity

Intensive agricultural systems typically have limited crop diversity. Many such systems are monocultures at least at the level of individual fields, and are relatively homogenous even at the regional level. Low crop diversity generally will mean both limited botanical diversity and limited structural diversity. (Robinson & Sutherland, 2002) analyzed changes in agriculture and biodiversity in Britain since the 1940s. They found a consistent reduction in landscape diversity, as reflected in a 65% decline in the number of farms. Farms had become more specialized and efficient. This also was associated with the removal of 50% of hedgerows and a reduction in winter stubbles. Hedgerows and similar non-cropped habitat are important sources of food and shelter for a variety of plants and invertebrates.

Reductions in landscape diversity lead to lower faunal diversity in intensively managed agro-ecosystems than in more diverse agricultural systems or in natural habitats. For example, (Robinson & Sutherland, 2002) found major declines in organisms associated with farmland in Britain and northwest Europe, particularly in habitat specialists. As an illustration, biodiversity declines in bird species were related to reduced food availability in the non-breeding season. They concluded that reduced habitat diversity was of particular importance in the 1950s and 1960s, while reduction in habitat quality may be more important now. Similarly, a review of the available literature on arthropod diversity found that structural biodiversity in agricultural areas is correlated with functional and species biodiversity of the above-ground insect fauna (Duelli et al., 1999)

Tillage

Intensive tillage leads to frequent disturbances of the agricultural landscape, increases energy loss from agricultural fields, and increases problems of soil erosion and run-off from agricultural fields. All of these factors adversely affect the quality of agricultural habitats, with significant consequences for agricultural biodiversity. When (Witmer et al., 2003) looked at corn, soybean and wheat cropping systems in the Mid- Atlantic region of the United States, they found that ground-dwelling and foliage-dwelling beneficial arthropods were least abundant, and pests were most abundant, in the simplest, most intensively managed continuous corn system. In general, ground-dwelling species were more abundant in no-till than in deep-tilled crops. This suggests that shifts toward conservation tillage and no-till will benefit agricultural biodiversity. As discussed in Section 2, such shifts have been occurring recently in many cropping systems as farmers recognize the environmental and economic benefits of doing so.

Pesticide use

Adverse effects of pesticide use in agriculture are well-documented (Pimentel & Lehman, 1993). Conventional insecticides generally reduce diversity through direct toxic effects. Many of the widely used classes of conventional insecticides, including organophosphates and pyrethroids, have been shown to adversely affect a broad range of non-target species, including species of economic importance. Local extinctions are common where these insecticides are frequently used. Such insecticides have been shown to eliminate important predator and parasitoid species from agricultural systems. In Indian cotton for example, over 600 such species have disappeared altogether. These impacts on natural enemies have been shown to lead to flare-ups in secondary pest species, some of which were not previously economically important. In a few cases, insecticides directly stimulate the population growth of non-target pest species, e.g. pyrethroids have such an effect on some mite and aphid species. In addition, the toxic effects of insecticides can lead to food chains effects because of decreased food availability for higher trophic levels and bioaccumulation of the insecticides. For example, organochlorine use and ingestion by earthworms has led to die-offs of birds feeding on these species. Replacing broad-spectrum insecticides with more specific, softer alternatives is necessary to avoid these impacts.

Some herbicides also can be toxic to invertebrates. However, the more important effects of herbicide use with respect to biodiversity are to reduce non-crop plant (weed) populations and weed seed production in agricultural fields. Where herbicide use is intensive, adverse impacts may be seen on various vertebrate and invertebrate species that depend upon these plant species for food or shelter. Where invertebrate populations are strongly affected, consequences for higher trophic levels also may occur.

Genetically modified (GM) crops

The use of GM crops can positively impact agricultural species biodiversity. In particular, the adoption of insect resistant Bt crops, expressing highly specific Bt proteins, represents an opportunity to replace broad-spectrum insecticide use. The insecticidal proteins expressed in Bt crops such as Bt maize and Bt cotton are so narrow in their activity that they have little or no activity against non-target organisms. Furthermore, the toxins are expressed within the plant tissues, minimizing the exposure to animals that do not feed on the crop plants. As a consequence, across the large number of field studies that have been conducted, few or no differences have been seen with respect to community structure or individual species abundances where fields of Bt crops have been compared to conventional crops that have not been treated with insecticides. Where they have been calculated, indices of species diversity and community structure have not differed significantly for Bt corn fields compared to untreated conventional corn fields (e.g., (Lozzia, 1999a; Lozzia, 1999b) (Dively & Rose, 2002) or for Bt cotton fields compared to conventional cotton fields ((Fitt & Wilson, 2003; Naranjo & Ellsworth, 2002; Naranjo et al., 2002; Xia et al., 1999). The only species that have been observed to be significantly and consistently less abundant in fields of Bt crops relative to fields of conventional crops are the target pests. In studies where the conventional crop fields have been sprayed for the target pest species of the

Bt crop (as routinely occurs in most crop systems), many non-target species have been observed to be adversely impacted, leading to significantly lower non-target populations in sprayed conventional fields as compared to Bt crop fields. With corn fields, this is particularly obvious for foliage-dwelling species because of the method of application of these insecticides, but ground-dwelling species like carabids and cursorial spiders are also often affected, directly or indirectly, by the insecticidal sprays and are apparently not affected by Bt corn (Candolfi et al., 2003); (Dively & Rose, 2002). Similarly, a variety of studies of Bt cotton in the United States, Australia and China have all demonstrated that populations of many non-target species are higher in Bt cotton fields than in sprayed conventional cotton fields (Fitt & Wilson, 2003; Head et al., 2001; Naranjo et al., 2002; Xia et al., 1999). Likewise, work on potato fields in the northeastern US has revealed larger populations of many generalist predators in Bt potato fields than in conventional potato fields treated with appropriate broad-spectrum insecticides (Reed et al., 2001).

The years long controversy on the fate of the monarch larvae in the US cornfields seems to be solved: After the first shock of the Nature publication of (Losey, 1999) extensive field work demonstrated no significant impact (Gatehouse et al., 2002; Hansen & Obrycki, 2000; Hellmich et al., 2001; Hodgson, 1999; Oberhauser et al., 2001; Pleasants et al., 2001; Sears, 2000; Sears & Boiteau, 1989; Sears et al., 2001; Sears & Shelton, 2000; Shelton, 2001; Stanley-Horn et al., 2001; Zangerl, 2001). It was Rachel Carson herself who named Bt proteins as a possible way out of the pesticide crisis which she described in her famous 'The Silent Spring', and one can only wonder what she would have said about the Bt toxin instead of being sprayed in large, but rapidly decomposing quantities built genetically into the corn borer infested crops (Carson, 1962 - 2002).

Herbicide tolerant crops are not expected to directly affect agricultural biodiversity because of the nature of the proteins expressed but they may lead to changes in practices that could affect biodiversity. Herbicide tolerant crops facilitate shifts toward reduced tillage, as observed for soybean and cotton in the United States. As noted earlier, such shifts can be beneficial to agricultural eco-systems.

In addition, herbicide tolerant crops permit greater flexibility in herbicide application practices, particularly the timing of applications. If these practices lead to more intensive and higher level weed control, then biodiversity may be adversely affected (Watkinson et al., 2000). However, herbicide tolerant crops also can encourage herbicide application practices that benefit wildlife. For example, studies on herbicide tolerant sugarbeet in the UK and Denmark have shown that leaving weeds untreated in the agricultural field for a longer period allow arthropod populations to increase to higher levels than are seen in conventional fields, without affecting crop yield (Dewar et al., 2002). These weeds and the associated arthropods provide valuable food and habitat for farmland birds and other wildlife. Such a practice is not feasible with conventional sugarbeets. Soil fertility can be enhanced with appropriate use of broad spectrum herbicide tolerant sugar beets (Elmegaard & Pedersen, 2001; Strandberg & Pedersen, 2002).

The fate of Bt toxin in the soil

It has been shown that Bt toxin is released into the rhizosphere soil with decaying litter and through root exudates from Bt corn (Stotzky, 1999). The insecticidal toxin produced by *B. thuringiensis* subsp. *kurstaki* remains active in the soil, where it binds rapidly and tightly to clays and humic acids. The bound toxin retains its insecticidal properties as determined by bioassays: the toxin is protected for some time against microbial degradation by being bound to soil particles, persisting in various soils for at least 234 days (the longest time studied). Unlike the bacterium, which produces the toxin in a precursor form, Bt corn contains an inserted truncated cry1Ab gene that encodes the active toxin. The toxins do not appear to have any consistent effects on organisms in soil (earthworms, nematodes, protozoa, bacteria, fungi) or on microorganisms *in vitro* (Koskella, 2002; Saxena et al., 1999; Saxena & Stotzky, 2001). A multiseason monitoring in six fields in the USA did not reveal any effect on various bioassays with soil organisms, using soil matter including degrading leafes (Head et al., 2002). A recent study (Zwahlen et al., 2003a; Zwahlen et al., 2003b) is focussing on bioassays with degrading leaf litter of two near isolines of Bt- and non-Bt-maize under controlled conditions. The study concludes that possible subtle, longterm toxic effects should be tested in long term monitoring in the post-commercialization phase. These possible effects should be put into quantitative relation to long term monitoring data under field conditions with non-Bt maize, where more pesticides are used.

There is a vast body of knowledge also on the use of Bt toxin as a biopesticide: (Glare & O'Callaghan, 2000)

Conclusions

Agricultural practices adversely affect in-field biodiversity in a number of obvious ways. Most of these practices can be effectively mitigated through judicious use of available technologies and crop management strategies. For example, GM crops can replace agricultural practices that would otherwise depress and disrupt species biodiversity, and can encourage or complement other practices that enhance biodiversity. Existing agricultural policies and other political factors also strongly affect the decisions made by farmers. That said, the potential exists to directly or indirectly reward farmers for making environmental improvements to their land (Mellor, 1995; UNDP, 2001).

Natural biodiversity

General impacts of modern intensive agriculture

As discussed in Section 1, experts generally agree that the factor most responsible for decreases in natural biodiversity, both locally and globally, is habitat destruction and fragmentation as land with native communities is cleared for agricultural or other use. The past 35 years have brought a 1.68-fold increase in the amount of irrigated cropland and a 1.1-fold increase in

cultivated land (Tilman, 1999). This problem is most severe in developing countries with a large amount of subsistence agriculture. Even looking within different agricultural systems, the degree of fragmentation increases with the intensity of agricultural management. For example, (Belanger & Grenier, 2002) showed that fragmentation increased along a gradient from traditional dairy agriculture to more intensive cash crop agriculture in the St. Lawrence Valley of Quebec, Canada.

Pesticide use

Pesticide use, and particularly insecticide use, has significant off-site effects on biodiversity. Aerial drift and movement in water can expose natural communities to potentially toxic amounts of pesticides. These effects will be most severe on communities adjacent to agricultural lands. (Boutin & Jobin, 1998) found the species composition in habitats adjacent to agricultural habitats to be adversely affected by intensive agriculture, as measured by tillage practices and pesticide and fertilizer use. These non-crop habitats adjacent to cropped land are critical for the maintenance of plant species diversity, for the conservation of beneficial pollinating and predatory insects, and as essential habitat for birds (Mineau & McLaughlin, 1996)

Tillage and fertilizer use

The impacts of tillage on biodiversity in agricultural fields were described earlier, the disruption of in-field communities and reduction of soil quality being the most obvious. However, the impacts of tillage on natural habitats are even greater. Soil erosion due to tillage leads to high levels of fertilizers and pesticides being carried off agricultural fields into waterways. Remember that the past 35 years have seen a 6.87-fold increase in nitrogen fertilization and a 3.48-fold increase in phosphorus fertilization within intensive agricultural systems (Tilman, 1999). As they move into aquatic systems, these chemicals can have direct toxic effects on natural communities, while the fertilizers cause eutrophication. Eutrophication leads, in turn, to direct losses in biodiversity, pest outbreaks, and changes in the structure of natural communities. In addition, because erosion leads to various forms of nitrogen and particulate matter being redistributed aerially, natural terrestrial ecosystems also are being eutrophied.

Many of these problems can be reduced or avoided by reducing tillage practices. In North America and Europe, high-yield farming and conservation tillage have reduced soil erosion by 65-98% (Buffett, 1996). However, subsistence farming in developing countries is causing substantial soil erosion and habitat loss, and is a significant threat to natural biodiversity.

Genetically modified crops

GM crops have the ability to benefit natural biodiversity in a number of ways. *First*, GM crops have the demonstrated potential to increase yields and decrease variability in yields (Gianessi et al., 2002) thereby reducing the need to put additional land into agricultural production. By slowing the rate at which natural habitats are destroyed, GM crops and other technologies that increase agricultural productivity can help to preserve natural biodiversity. *Second*, insect resistant crops reduce the use of broad-spectrum insecticides that

would otherwise have direct and indirect effects on natural communities dwelling near agricultural fields. The insecticidal proteins expressed in Bt crops are both highly specific and contained within plant, minimizing the possibility of any off-site effects due to spray drift. *Third*, herbicide tolerant crops facilitate a reduction in tillage, thereby reducing soil erosion, eutrophication and contamination of aquatic communities (see earlier discussion of the impacts of tillage and the following chapters on the impact of GM crops on genetic diversity).

Conclusions

The greatest threat to natural biodiversity comes from habitat loss, much of which is driven by agricultural demand. Increasing the productivity of land currently in production is necessary to slow this process. Other agricultural practices also can negatively impact natural communities through various off-site effects, including movement of fertilizers into aquatic systems and pesticidal drift. Reducing tillage and decreasing the use of pesticides can mitigate some of these impacts. GM crops can be a partial solution to several of these problems; GM crops enhance productivity, minimize off-site effects, and (in the case of herbicide tolerant crops) facilitate reductions in tillage.

Impacts on Genetic Diversity

Crop genetic diversity

General impacts of modern intensive agriculture

As observed earlier, conventional agriculture is characterized by the use of highly productive varieties generated through breeding programs, and low crop species diversity. Because the number of varieties of any given crop maintained by breeding programs necessarily will be limited, this focus has led to a steady loss of genetic diversity in crop species and the permanent loss of many varieties over the last 100 years. This issue has been the motivation for the establishment of genetic archives for many important crop species.

Genetically modified crops

Biotechnology represents a tool for enhancing genetic diversity in crop species through the introduction of novel genes. These same genes, and their associated traits, could not be introduced through any other process, such as conventional breeding. However, with the introduction of these traits, concern has been expressed that overall genetic diversity within crop species will decrease because of breeding programs maintaining a smaller number of high value cultivars. A number of studies have specifically focused upon this subject and they have concluded that the introduction of transgenic cultivars in agriculture has not significantly affected levels of genetic diversity within crop species. For example, (Sneller, 2003) looked at the genetic structure of the elite soybean population in North America, using coefficient of parentage (CP) analysis. The introduction of herbicide tolerant cultivars with the Roundup Ready trait was shown to have had little effect on soybean genetic diversity because of the widespread use of the trait in many breeding programs. Only 1% of the variation in CP among lines was related to differences between

conventional and herbicide tolerant lines, while 19% of the variation among northern lines and 14% of the variation among southern lines was related to differences among the lines from different companies and breeding programs. Similarly, when (Bowman et al., 2003), examined genetic uniformity among cotton varieties in the United States, they found that genetic uniformity had not changed significantly with the introduction of transgenic cotton cultivars. In fact, when they compared the years before and after transgenic cultivars were introduced, they observed that both the percentage of the crop planted to a small number of cultivars and the percentage planted to the most popular cultivar had declined. Thus genetic *uniformity* actually decreased by 28% over the period of introduction of transgenic cultivars.

Conclusions

Preservation of the genetic diversity present in crop species is an important need being addressed by various public and private programs. In this respect, biotechnology can be a valuable tool for introducing novel genes. Furthermore, the development and introduction of GM crop varieties does not represent any greater risk to crop genetic diversity than the breeding programs associated with conventional agriculture.

Natural Genetic Diversity

General impacts of modern intensive agriculture

Conventional agriculture has adversely impacted the genetic diversity and population structure of many wild plant and animal species, with severe implications for the conservation of many species and ecosystems. The greatest impact has come through direct loss of natural habitat. As land is put into agricultural production and natural habitats are destroyed, the habitat available to any particular species will become limited and more fragmented. This, in turn, will reduce the effective population size of many species, potentially reducing genetic diversity to critical levels and causing inbreeding that can have additional adverse effects on the fitness of populations.

Putting land into agricultural production and fragmenting the available natural habitat also can limit gene flow among populations of a species. Where individuals of an animal species are unable or unwilling to move through agricultural fields, populations will become more isolated, further reducing effective population sizes and threatening the viability of these populations.

Agricultural strategies all have the goal to produce food, and most claim to do this in a sustainable way. What is the connection between biodiversity and sustainability? There is no clearcut positive connection regarding agricultural and natural productivity, but we have hints that pest problems can be reduced through better management of biodiversity: Some weeds are also important hosts of beneficial insects which reduce the populations of pest insects. (Nentwig, 1999). On the other hand, weeds create problems of adding toxins to yield. (Beck et al., 1999). And claims, that on the long run herbicide tolerant crops could be harmful to the biodiversity of a whole landscape including bird fauna have been questioned.

(Johnson, 2000) "The irony is that biotechnology may hold the key to less damaging forms of agriculture, yet it appears that it is currently being used by some parts of the industry in some countries to produce the opposite effect. We are challenging the industry to change direction in R&D, toward producing crops that contribute to more sustainable forms of agriculture, demonstrating real and tangible benefits for the environment. I believe this needs to be done wherever the products of biotechnology are intended to be used, whether in industrial or developing countries."

Recent results (Elmegaard & Pedersen, 2001; Strandberg & Pedersen, 2002) contradict the above cited statements: The results reveal that the implementation of Roundup Ready fodder beets may increase biodiversity in beet fields. In general, the weed flora and arthropod fauna in RR plots contained more individuals and species than the T plots in June.

Organic agriculture tends to enhance biodiversity on the field on cost of yield, but energy input is also lower (Mäder et al., 2002), (Stokstad, 2002), (Zoebl et al., 2002), (Goklany, 2002). Despite of persisting scepticism against new agricultural strategies (organic or biotech), there is a lot of potential to discover in making food production still more ecological. It remains to be shown how widespread organic farming in large areas can effectively control pests. Still, the vision is justified to develop new GM crops, better adapted to the local ecological conditions, this reducing fertilizer use, pesticide use and enhancing biodiversity directly through more crop diversity and indirectly through enhancing biodiversity in the fields.

Gene flow between crops and to wild relatives

Planting of crop species in close proximity to wild, sexually-compatible relatives will permit gene flow between the crop and wild relative. Typically this process will have little direct effect on the genetic diversity of the wild relative because of the limited ability of most crop species to outcross over significant distances. However, even though the amount of gene flow will usually be low, it is possible that this process could lead to the transfer of genes that code for traits with significant impacts on fitness of the recipient plants. This should not adversely affect the wild species because traits associated with decreased fitness will be rapidly selected out of the recipient population but, if fitness is greatly increased, then weedy characteristics of the wild relative could be enhanced. Such an effect could cause indirect negative effects on natural plant communities and the animals dependent upon them.

There is a plethora of studies and summaries of research results, which all demonstrate that no harmful effects on the environment have been detected in relation to out crossing. Basically, we have the same phenomena as with non transgenic crops. There are possible scenarios imaginable, where an escaped transgene could permanently initiate a selective advantage, but so far this has not occurred. It is also difficult to imagine such a scenario, since agricultural traits have transgenes inserted, which are useful only in the artificial environment of intensive agriculture. Reviews are available as reports from the European Community: (Eastham & Sweet, 2002). The conclusions are vague and cannot reveal a single case of a negative impact.

The possible implications of hybridization and introgression between crops and wild plant species are so far unclear because it is difficult to predict how the genetically engineered genes will be expressed in a related wild species. The fitness of wild plant species containing introgressed genes from a GM crop will depend on many factors involving both the genes introgressed and the recipient ecosystem. While it is important to determine frequencies of hybridization between crops and wild relatives, it is more important to determine whether genes will be introgressed into wild populations and establish at levels which will have a significant ecological impact.

The study is done in the best reductionistic tradition, relying 100% on measurements of escaped transgenes in the field, which automatically means that only short term results have been interpreted – with all its limitations (bias on weather conditions, local and regional topographic conditions etc.)

An comprehensive review has recently been given by (Messeguer, 2003) with a balanced view, warning of unfounded generalizations. Negative generalizations are also not supported by facts, although (Ellstrand, 1992) reflects on the possibility to do better in agro ecology of the future, since the transgenes and other molecular markers offer a much more precise picture of the dynamics. A method to assess long term potential gene flow is given by (Frietema, 1996) and by (Ammann et al., 1996) and (Ammann et al., 2000a), making use of the excellent 'databases' of herbaria, collections of vast amounts of crops, their wild relatives and their well documented (and often over-represented) hybrids. With the help of morphometric analysis and subsequent field excursions with testing molecular markers in hybrid zones, with experimental hybridization, it is possible to give a reliable overview of potential gene flow in a given region.

As discussed previously, the use of highly productive transgenic cultivars can ameliorate the adverse impacts of conventional agriculture on the genetic diversity of wild species by limiting the land area being converted to agricultural production. In addition, by replacing broad-spectrum insecticides, the use of transgenic cultivars may permit greater levels of movement of non-target species through agricultural habitats, thereby reducing the degree of habitat fragmentation caused by agriculture.

Where transgenic cultivars are grown near wild relatives, the transgenic event may be transferred to the wild relative. At least with currently commercialized GM crops, no significant impact on the wild species is expected because the traits involved should not affect the fitness of individuals of the wild species. The long term experiment with four GM crops in England and a given set of transgenes suggest that competitiveness of the wild relatives outside the field prevents survival of the GM crops after a few years: (Crawley, 1999; Crawley et al., 2001; Crawley et al., 1993).

The case about the Mexican corn gene flow

The paper "Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico (Quist & Chapela, 2001), rose a worldwide debate about it's

results and abuse of science for political rather than for scientific discussions, despite early publications on the same matter, which did not raise concerns (Martínez-Soriano & Leal-Klevezas, 2000). Some of the rebuttals of the paper were published: (Aldhous, 2002; Berne Debate, 2002; Christou, 2002; Hodgson, 2002; Kaplinsky, 2002; Mann, 2002; Martínez-Soriano & Leal-Klevezas, 2000; Metz, 2002; Pauli, 2002; Quist & Chapela, 2002; Salleh, 2002; Wager et al., 2002). Nature's editor Philip Campbell reacted with an editorial note in the issue of April 4, 2002 (Campbell, 2002). This editorial note does not correct or retract the publication but admits: "Nature has concluded that the evidence available is not sufficient to justify the publication of the original paper."

The initial publication and the scientific debate rose amazing anxiety among the opponents, they attacked all those, who questioned the results of Quist/Chapela to be 'notorious pro GE-scientists' denigrating the possibility of transgene flow in Mexico, which is certainly not the case. Here a sample of such unfounded allegations taken from AgBioView, circulated on Debate: (Prakash, 2002). It is all the more astounding that evidence of gene flow is published manifold, although somehow difficult to find: (Kato, 1997; Kermicle, 1997), the url is still active:

http://www.cimmyt.org/ABC/Geneflow/geneflow_pdf_Engl/contents.htm.

Despite the factual and scientifically proven gene flow from modern traits towards teosinte and maize landraces there is evidence of stability among the landraces and their wild relatives and no negative processes were detected.

Today, the fact is confirmed, that transgene flow also has happened in Mexico, and the Mexican Government is still working on the case to sort out more details about the provenience of the transgenes. A reliable summary has been given by (Alvares-Morales, 1999).

The case of herbicide tolerance in wild species induced by hybridisation with herbicide tolerant transgenic crops (Madsen, 1994) tested the competitive ability and growth behaviour of a hybrid between sea beet (*Beta maritima*) and transgenic sugar beet (*Beta vulgaris*) with a glyphosate resistance. She tested in a field experiment whether the hybrid had a higher biomass and a higher competitive ability than the non-transgenic parental types. The hybrid did not produce more biomass than sugar beet and the competitive ability of the hybrid did not exceed the expected level of a non-transgenic hybrid between sugar beet and sea beet. In the general discussion of herbicide resistance evolving herbicide resistant weeds, Madsen concludes that during herbicide applications, selection pressure from e.g. glyphosate is posed on the population privileging herbicide resistant types what should be prevented by crop- and herbicide-rotation. This fits well into the case study of *Brachypodium* by (Gressel, 1994) where certain herbicide types developed mutational resistance of a weed which was

problematic only during herbicide application: 6 years after the application stop the resistant grass mutants have been totally out competed.

The first author came to positive conclusions some years later: (Madsen & Sandoe, 2001) "Risk assessment studies of herbicide resistant sugar beet have revealed no risks to human health or the environment. Indeed it appears that commercial growth of this crop might secure benefits such as decreased pesticide use and increased biodiversity." Considerations for the release of herbicide tolerant crops have been published by (Bainton, 1993). The author concludes that, although there are no grounds for major concern, but the Ministry of Agriculture, Fisheries and Food of the United Kingdom should remain alert to adverse developments and be ready to investigate any matters to which the Advisory Committee on Releases to the Environment draws attention.

Regarding (semi)natural habitats, (Crawley, 1993) and (Timmons et al., 1996) acclaim that a herbicide resistance outside the arable land does not provide an advantage to a wild relative, because there is no selection pressure in favour of herbicide resistance in natural habitats. For more details see (Carpenter et al., 2002). (Sukopp & Sukopp, 1993) add that there are other odds against a rapid spread of crops in natural habitats: Long term observation experience of traditional weeds of agricultural systems show that these species are often nicely confined to areas strongly influenced by man. Massive application of herbicides has led to the development of numerous herbicide resistant weeds up to now.

Enhanced weediness in transgenic crops?

In their often cited PROSAMO field study (Crawley, 2001) showed that the analysed transgenic varieties of oilseed rape were slightly less competitive than traditional ones. Considering population biology, the analyses can be criticized in the way that just mean values are discussed. (Weber, 1995) demands in her critical, but purely theoretical discussion of (Crawley, 1993) that risk problems accessible to empirical verification should actually be approached empirically. This has been done extensively in the meanwhile, as summarized by (Sweet et al., 1999):

Detection of herbicide tolerance in seed of male sterile oilseed rape plants at distances of up to 400m show that there is potential for oilseed rape pollen to be dispersed by wind and remain viable over considerable distances.

Numbers of volunteers recorded at National List sites were low and it is evident from these results that GM herbicide tolerant oilseed rape does not appear to increase problems of volunteer management in following crops. A proportion of seeds sampled from GM plots were hybrids expressing tolerance to both glufosinate and glyphosate but there was no indication that these multiple tolerant hybrid plants were more difficult to control in following crops than conventional or single tolerant rape varieties.

The numbers of glufosinate tolerant compared to non-GM volunteer plants found both in following crops and in field margins were low at the Plant Genetic Systems Cambridgeshire site. Previous work looking at the survival and persistence of GM rape lines reflects the situation reported here (Booth, 1996; Crawley, 1993; Sweet, 1997) Incidence of GM herbicide tolerant rape plants in these volunteer populations suggest that weediness and invasiveness is not enhanced by this specific genetic modification.

(Sukopp & Sukopp, 1994) p. 67 stated that:

After three years running time the following results can be seen (Crawley et al. personal communication and (Crawley, 1993) Transgenic and non-transgenic crops (oilseed rape, potatoes, maize) have the same competitiveness outside agro systems. They hardly can persist more than one generation. In no case sexual reproduction has been observed.

Since there are only a few long term monitoring on transgenic crops existing which concentrates on weediness in all aspects, scenarios must momentarily remain speculative, see concepts cited in (Ammann et al., 1999) There are more details about potential weediness and GM crops discussed in (Ammann et al., 2000b)

According to (Fredshavn, 1994; Fredshavn J.R., 1995; Fredshavn, 1992; Fredshavn & Poulsen, 1994) the environmental consequence of releasing transgenic plants to unconfined conditions depends on the changes in survival rate, growth behaviour and hybridisation possibilities caused by the transformation.

Survival rate depends on the growth conditions: soil type, water and nutrient supply and plant cover. Crucial for invasion of natural habitats is the establishment period immediately after the seed has germinated („the child mortality“). Later the competitiveness of the plant determines the success as an invader. Fundamental changes in growth behaviour may allow the plant to invade new habitats not formerly occupied by the non-transformed genotype, but more likely, the growth behaviour is only slightly modified, and the transformed plant is limited to the same habitats as the non transformed genotypes.

Such phenomena concerning sensitive developmental phases should be considered when planning a long term monitoring system.

From the literature, (Madsen, 1994) concludes that there is no evidence that herbicide tolerant crop plants should become weeds, unless they already possess the traits for weediness, and if only one herbicide is used consecutively in several crop rotations for a longer period of time.

Long before transgenic herbicide tolerant crops have been a concern, (Rauber, 1977) pointed to the possibility of negative consequences: The following scenario developed by Rauber is still valid today.

“New developments are made possible with the availability of modern herbicides: Their impact lacunas produce ecological niches for resistant populations. A possible future problem is that new weeds could emerge from hybrids from crops and their wild relatives (cultivated and wild oat) and also from the crops themselves (sugar beet and weedy beet). In spite of or because enhanced precision physiological and ecological selectivity of future herbicides, it will be more and more difficult to fight these new tolerant varieties. They will have the same genome as the cultivar, except for at least one allele causing weediness. Possibly there will be some future annual weeds, developing as a perfect mimicry to crops, in this way reaching back to prehistoric times where weeds and crops were still very close and connected through a full range of intermediate forms in fields and seed mixtures.”

However there are scenarios which could hint to gene flow causing more fitness in certain wild relatives of transgenic crops: (Alexander et al., 2001) and (Snow, 2003): In a field experiment crossing cultivated and wild sunflowers, the resulting hybrids that contained the Bt transgene had 50 percent more seeds than control hybrids. It is not known whether the crossing experiments also included the true null-hypothesis: crossing non-transgenic cultivars with the wild relatives.

Interpreting and Misinterpreting Science

Some basic remarks at the end of this introductory chapter: It is a widespread misconception, even among learned ecologists, to treat agricultural systems the same way as natural ecosystems when planning ecological field experiments. This cannot be supported scientifically, since both types of ecosystems have fundamental differences, as described above. It is therefore not feasible to apply the same ecosystem and biodiversity standards in both cases. Agricultural systems are highly artificial and certainly show a much higher dynamics through manifold farmer activities such as tilling, sowing, harvesting, crop rotation (to name the ones having the most dramatic impact on biodiversity). This is why reports such as the one of Ecostrat, (Hilbeck et al., 2000) commissioned by Greenpeace are written in the wrong perspective: First all the open questions should be answered which can be posed in the perspective of basic ecological research, then maybe in a distant future after many years of research it might be possible to release transgenic crops. The Ecostrat report deals with the early phase of US regulation, field experiments were done for the purpose of getting approvals, but some of those early experiments lack sound statistics and do not deal enough with the intricate ecological web of life in the production fields. Still, de Greefs rebuttal seems justified in the light of new field research:

(de Greef, 2000) „The environmental impact of Bt maize, including the impact on non-target insects, is part of this safety assessment and of ongoing work. The overwhelming body of scientific evidence supports the view that non-target insect populations are not at risk from Bt maize.“

"compared to crops treated with conventional chemical pesticides, the transgenic crops have no detrimental effect on a substantial number of individuals in beneficial insect populations."

"The US Environmental Protection Agency (EPA) has recently released a Fact Sheet on Novartis Bt maize. In it, it outlines the evaluation done on Bt maize, including studies done on ecological effects and effects on non-target beneficial organisms. It includes a formal review of studies done by Hilbeck, one of the authors of the EcoStrat report, on the effects of Bt maize on the green lacewing, a beneficial insect. The EPA concludes, "the results of these studies do not support the conclusion that the Bt toxin was directly responsible for the observed differences in lacewing mortalities." Furthermore, they conclude "compared to crops treated with conventional chemical pesticides, the transgenic crops have no detrimental effect on a substantial number of individuals in beneficial insect populations."

Another typical case of such misinterpretation is the scientific report on the Chinese Bt cotton by Greenpeace: Again the problems are approached with the same wrong optics of mixing up natural and agricultural habitats: (Xue,

2002), the rebuttal: (Gathmann & Bartsch, 2002), including several replies, also the one of Dr. Wu, who, as an author of the original study, has been misinterpreted by Greenpeace: He is a member of the National GMO Biosafety Committee. According to Dr. Wu, his results "strongly oppose the major conclusions in Greenpeace's report and do not support their views." Dr. Wu specifies in this reply results of Chinese Bt-research from 1997 to 2001, which show efficient pest-control and reduced chemical insecticide use by Bt-Cotton. The Greenpeace editors interpreting Wu's work seem not to be aware of the fact, that if pest insects are effectively controlled their parasites also show a dramatic decline, which cannot per se being interpreted as a negative impact (Rufner Al Mazyad & Ammann, 2002). Finally, it should now be clear, that from the agronomic point of view ecological research done in the lab with forced feeding experiments reveal valuable insights in the food web (Hansen et al., 2001; Hilbeck, 2001), but those results need to be confirmed under real time and real locality conditions.

(Sears et al., 2001): Previous reports ((Hansen & Obyrcki, 2000; Losey, 1999) indicating the hazard of *Bt* corn pollen to monarch butterfly are inadequate to assess risk, because assigning risk can be accomplished only when the likelihood of toxic response can be properly expressed and the likelihood of exposure is estimated through appropriate observations. We have used a comprehensive set of new data and a formalized approach to risk assessment that integrates aspects of exposure to characterize the risk posed to monarch from *Bt* corn pollen. Characterization of acute toxic effects alone indicates that the potential for hazard to monarchs is currently restricted to event 176 hybrids, which express Cry1Ab protein in pollen at a level sufficient to show measurable effects. Event 176 hybrids have always had a minor presence in the corn market and current plantings, which comprise, 2% of corn acres, are rapidly declining. Other events either express negligible Cry1Ab protein in corn pollen (Mon810 and Bt11) or express Cry protein of significantly less toxicity to monarch (Ddt418, Cbh351, and Tc1507 expressing Cry1Ac, Cry9c, and Cry1F proteins, respectively). Chronic exposure to *Bt* pollen over the entire larval growth of monarchs has not been documented in these studies and may reveal sensitivity to Cry proteins not accounted for here. Monarch populations share their habitat with corn ecosystems to a degree previously undocumented (4). Despite this, the portion of the monarch population that is potentially exposed to toxic levels of *Bt* corn pollen is negligible and declining as planting of event 176 hybrids is phased out through 2003. Because the effects portion of the risk probability equations described above (P) is such a small value for the dominant corn hybrids currently planted, the sensitivity of the model to factors describing ecological exposure (P_e) and for risk (R) will remain low. Evidence supporting this risk conclusion has been collected. Evidence supporting this risk conclusion has been collected over a wide geographic area and under a variety of conditions in both laboratory and field settings (Hellmich et al., 2001; Oberhauser et al., 2001; Pleasants, 2001). Findings from studies done in multiple locations were consistent, even though methods differed from one study to another. This approach to risk characterization is consistent with accepted risk assessment procedures and shares many similarities with previous assessments over a wide range of situations describing potential risk associated with a described hazard. It is imperative that future conclusions concerning the environmental or nontarget impacts of transgenic crops be based on appropriate methods of investigation and sound risk-assessment procedures.

Even though, field results have the potential to show great variation, which is shown as an example with Bt maize pollen deposition on leafes under field condition (Byrne et al., 2003).

What really counts in growing GM crops, is the actual toxicity impact under field conditions, and this impact has been shown to be negligible (Sears et al., 2001; Sears & Shelton, 2000; Shelton, 1999; Shelton, 2001).

Conclusions

Habitat loss and fragmentation represent the greatest threats to natural genetic diversity. Practices that increase the productivity of existing agricultural lands will help to limit these effects. (UNDP, 2001). GM crops can be useful in this respect. Preservation of the genetic diversity present in crop species is an important need being addressed by various public and private programs. In this respect, biotechnology can be a valuable tool for introducing novel genes or valuable genes from old cultivars. Furthermore, the development and introduction of GM crop varieties does not represent any greater risk to crop genetic diversity than the breeding programs associated with conventional agriculture. The view, early published by the (National-Research-Council, 1989), that GM crops offer more precision in lab and field testing than conventional ones has not been disproven to date.

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