IMPACTS OF BIOTECHNOLOGY ON BIODIVERSITY

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ABSTRACT

Biodiversity is threatened by agriculture as a whole, and particularly by traditional methods of agriculture. Knowledge-based agriculture, including GM crops, can reduce this threat in the future. The introduction of no-tillage practices, which are beneficial for soil fertility, has been encouraged by the rapid spread of herbicide-tolerant soybeans. The replacement of pesticides through Bt crops is advantageous for the non-target insect fauna in test-fields. Biodiversity differences can mainly be referred to as differences in herbicide application management.

INTRODUCTION

The Convention on Biological Diversity requires that all Member States take measures to preserve both native and agricultural biodiversity. The intrinsic value of species and ecosystems, in addition to their value as starting material for finding new products, is the basis for these measures.

The biggest threat to biodiversity is habitat destruction. The ever-increasing spread of cities and the accompanying expansion of agriculture must be held largely responsible. Humid tropical forests are particularly valuable reservoirs of biodiversity and are currently being seriously threatened. As the human population expands, the need for food is expected to double in the next 30 years, with the ensuing threat of massive habitat destruction particularly in the less developed countries. Increasing crop productivity on the land already under cultivation would prevent or at least reduce habitat destruction. One of several measures aimed at increasing yields is the use of better seeds, including those enhanced by modern biotechnology. Many other measures from the technical, socio-economical and political fields need to be taken up at the same time in order to balance intensification and sustainability of modern agriculture.

AGRICULTURAL BIODIVERSITY

In addition to biodiversity in the wild, there is the biodiversity of organisms used for farming and other human activities. 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 (Haywood 2000). Within these dominant crop species, there are many hundreds and thousands of varieties (landraces, cultivars) adapted to local climates, farming practices and cultural predilections like taste, colour, 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 programmes. The top three crops are wheat, rice and maize (corn) with around 500 million tonnes annual production each. Traditional breeding led us into the trap of narrowing down genomes, and perhaps wisely used biotechnology could bring back at least that part of genetic diversity, which enhances pest resistance and also yield.

There are many indications that mixtures of varieties of a crop or of different crops may give higher yields and be more resistant to pests and diseases than monocultures (Zhu, 2000) for rice in China. However, even in mixed cultures, high quality, well defined varieties and pure seeds are required and the sustainability of mixed cropping related to pest management has still to be proven. In addition, it is still not clear, whether or not, in natural, non-agricultural habitats yield is dependent on biodiversity. Based on experimental results, some researchers claim that the loss of species leads to a reduction in biomass, while others disagree, as demonstrated by Hector (1999) and Kaiser (2000). There simply may not be valid correlations between biodiversity and biomass yield, in either agricultural or non-agricultural settings.

LOSS OF BIODIVERSITY THROUGH TRADITIONAL AGRICULTURE

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) of the Convention on Biological Diversity ranked threats to global biodiversity as follows:

(i) Habitat loss: probably the most serious of all threats to biodiversity.

(ii) Introduction of exotic species.

(iii) Flooding, lack of water, climate changes, salination and so on, all of which can be either natural or man-made.

The unchecked rapid growth of human populations has had dramatic effects on biodiversity worldwide. Habitat loss owing to the expansion of human activities is identified as a major threat to 85% of all species described in the IUCN (World Conservation Union) Red List. The main factors are urbanisation and the increase in cultivated land surfaces. The shift from natural habitats towards agricultural land must have been dramatic in past times. The spread of wheat in Europe must have changed habitats and landscapes thoroughly and irreversibly over thousands of years (Ammann and Ammann, 1999). Agriculture had far-reaching effects on human society, spreading across Eurasia and leading to increased populations and eventually to civilisations such as those of classical Greece and Rome. But most of this happened centuries before the invention of writing, so it is only through archaeology that we can understand prehistoric agriculture (Ammann *et al.,* 1999).

IMPACT OF AGRICULTURAL BIOTECHNOLOGY ON BIODIVERSITY

With the introduction of GM crops, concern has been raised that overall genetic diversity within crop species will decrease because breeding programmes will concentrate on a smaller number of high value cultivars.

The introduction of herbicide-tolerant cultivars the trait was shown to have had little effect on soybean genetic diversity because of the widespread use of the trait in many breeding programmes. Only 1% of the variation in CP among lines was related to differences between conventional and herbicide-tolerant lines, whereas 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 programmes. Similarly, when Bowman *et al.* (2003) examined genetic uniformity among cotton varieties in the USA, they found that genetic uniformity had not changed significantly with the introduction of transgenic cotton cultivars. Genetic uniformity actually decreased by 28% over the period of introduction of transgenic cultivars.

REDUCTION OF BIODIVERSITY

The loss of biodiversity can be measured by a loss of individual species, groups of species or decreases in numbers of individual organisms. In a given location the loss will often reflect a degradation or a destruction of a whole ecosystem. Recently the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) of the CBD ranked the priority of threats to global biodiversity in the following manner: first comes habitat loss (most of it through the expansion of cultivated land), second comes the introduction of exotic species. Habitat loss comes not only from taking more land under the plough, but also from expanding cities and road building. In addition, habitats can be damaged by flooding, lack of water, climate changes, salination, etc., all of which phenomena that may be both natural or man-made. Since tropical humid forests are particularly rich in biodiversity, their destruction is disproportionately damaging to biodiversity. It is estimated by Pimm and Raven (2000) that, of the original 16 million

km^2 of these forests known a century ago, only half are left, with about one million km^2 being destroyed every 5 to 10 years. Burning and selective logging may damage an even greater area. Biodiversity is not homogeneously distributed over the humid tropical forests, rather there are hotspots with a particularly high level of biodiversity. These hotspots are of particular interest for the implementation of conservation measures.

The second most important reason for the loss of biodiversity is invasion by exotic plants and animals. Knowingly, or unknowingly, imported plant species threaten the native ones by being highly competitive and often by lacking local predators, such as insects or birds. 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. This invasion was brought about by European farmers who introduced animals and crops, in addition to accidentally spreading many different weeds. This phenomenon was already noted in 1833 by Charles Darwin. Today, still, droves of gardeners transport seeds all over the globe and never think of the possible threat to biodiversity, as suggested by Ammann (1997). It has been estimated that one in ten imported plants may spread in a modest way and that one in a hundred may turn into a nuisance weed. Even in today's Europe, invasion by exotics may threaten ecosystems. In the Ticino region of Southern Switzerland *Robinia pseudoacacia*, a native of North America is displacing chestnut and oak trees, whilst in the Northern regions of the country *Solidago canadensis* is replacing native irises in swampy areas. Islands are particularly threatened by invaders, as is well documented for Hawaii, New Zealand

and the Galapagos Islands. For North America, it has been estimated that the damage caused by exotics amounts to 137 billion dollars a year. Although such calculations are fraught with uncertainties, there is no doubt that the costs of exotics are tremendous. Exotic biological control agents are often introduced to agricultural ecosystems on purpose, in order to control pests or weeds without resorting to chemical control agents. Whilst there are some success stories, Strong (2000) pointed out that such systems may also go wrong. One example is the introduction of the seven-spot ladybird, which was intended to fight the Russian wheat aphid. The consequence, however, was the disappearance of the native ladybirds, for which the seven-spot imported was a competitor and an actual predator. Another example is the decimation of the large American moths, which are killed by European *Compsilura* flies, introduced nearly a century ago to control the gypsy moth. Field experiments recently done by Jensen showed that caterpillars of the American moth *Cecropia* were killed by massive infestations of *Compsilura* maggots.

It cannot be said today, on the basis of experimental evidence, whether transgenic plants are specifically prone to spreading in the long term. However, one would not expect this to be the case unless the transgenic plant had an increased fitness. There is no good argument why crops that have for centuries depended for survival on human care should become weeds, just because of the addition of one or a few well characterized genes, in addition to the many thousands of genes they already carry. However, this issue needs to be carefully studied on a case by case basis, keeping in mind that the absence of a negative effect can never be proven with absolute certainty. The results of a fairly long-term study of the performance of transgenic crops in natural habitats (Crawley, 2001), four different crops (oilseed rape, potato, maize and sugar beet) were grown in 12 different habitats and monitored over a period of 10 years. Showed that in no case were transgenic plants found to be more invasive or more persistent than their conventional counterparts, in agreement with the general hypothesis put forward above.

CONSERVATION STRATEGIES

Conservation may be *in situ* or *ex situ*, either in the natural or semi-natural habitat, or in some purpose-built environment. The choice of one or the other technique, or a combination of both, will depend on the particular case. *In situ* conservation will involve the maintenance and protection of natural habitats, while botanical gardens and seed banks are used for the *ex situ* conservation. Both of the latter require a precise knowledge of taxonomy. Conserving a substantial, but selected fraction, of the humid tropical forests would still allow half or so of their indigenous species to be preserved. This would require a selection of the most appropriate areas, called the hot spots. Protecting huge tracts of land will pose major socio-economic and political problems. It has been asked how forests destined to be protected from human encroachment can be kept free of hungry people in search of potential farmland (Mace, 2000). Jennings thinks that a viable strategy may be to find a sustainable livelihood for rural populations in connection with conserving tropical humid forests. Policing alone will not be successful over vast territories, as seen today in the war on drugs in South America and Asia.

Today, conservation also embraces various components of agro-biodiversity like crop varieties, land races, semi-domesticates and crop relatives. The role of indigenous communities in maintaining agro-biodiversity is stressed by the Global Biodiversity Assessment and the Leipzig Plan of Action, two recently concluded international agreements.

APPLICATIONS OF BIOTECHNOLOGY AND ITS EFFECT ON BIODIVERSITY

The methods of biotechnology can be applied to the study of virtually any biological phenomenon and will, in some cases, have practical applications for maintaining biodiversity. Conversely, threats to biodiversity by biotechnology also need to be considered.

BIOTECHNOLOGY FOR THE ACQUISITION OF KNOWLEDGE

In the context of this paper there are two quite different applications of biotechnology, or of molecular biology, that are relevant. The first is the use of biotechnology as a tool for acquiring knowledge, whilst the second is the use of biotechnology to directly intervene in plant and animal breeding, in particular to transfer genetic information from one sort of organism to a particular crop, or to a farm animal to make it transgenic.

Today, biological research can hardly be conducted without using biotechnology in one way or another. Taxonomy uses molecular markers to identify individual strains of organisms or to identify species, much in the same way as in forensic medicine to identify criminals. This is useful for *ex situ* conservation of plants and micro-organisms. In seed banks, (*Culture Collections and Gene banks*), genetic fingerprints are used to establish the origin of a seed or the relatedness of one plant variety to another. A rational classification of most micro-organisms has only become possible with these biotechnological methods. This is important to the many collections of micro-organisms that exist around the world.

Biotechnology has also proven useful for following genetic markers in plant and animal breeding. Here, animal or plant varieties are crossed by conventional, sexual means. By analyzing a few cells of the newly born calf or of the newly sprouted crop, one can predict some of the expected properties of the progeny, by looking at the presence or absence of certain forms of genes. This enables one to predict a phenotypic property, which will only show up later in life, for instance certain characteristics of a cow's milk or the crop's expected resistance to an infectious plant disease. Using *in vitro* fertilization of animals, the laboratory test can be done even before the embryo is implanted. This is called pre-implantation diagnostics.

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 a 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.

DIRECT GENE TRANSFER TO CROPS AND FARM ANIMALS

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 transgenic. From the time this simple strategy was devised, it took molecular biologists about twenty years until the first transgenic plants were made in 1985. Ten years later, the first transgenic crop appeared in supermarkets in the USA, the "FlavrSavr" tomato. In 2000, there were worldwide about 45 million hectares planted with commercial transgenic crops.

Most transgenic crops planted commercially in 2000 were in the US, Canada, Argentina, with smaller amounts in China, Australia, South Africa, Mexico and Spain. Soyabean and corn ranked first and second, making up 57 percent and 22 percent respectively of the total area planted with GMOs. Cotton and canola accounted for about 5.3 and 2.8 million ha each, whilst only small areas of transgenic potato, squash and papaya were grown commercially. With regards to the genetically-modified traits, herbicide tolerance was dominant with 74 percent, while insect resistance was 19 percent. According to the ISAAA, the amount of virus resistant crops was quite small. Compared to 1999, there was an increase of 10 percent in the area planted with GMOs. For corn there was a decrease, presumably because of an anti-GMO-wave that started in Europe in early 1999, soya and cotton showed an increase.

The reason that US farmers have adopted the transgenic crops surprisingly quickly is because of the economic benefits they offer. In most surveys done by different researchers in different parts of the US, the yields were the same or somewhat higher with the new seeds. The most noticeable difference to the farmers was the saving on herbicides. The US National Center for Food and Agricultural Policy cited an annual saving of US$ 220 million to soyabean farmers. It was also found that the new crops needed less frequent sprayings and allowed "no till" management. These benefits mostly offset the initial higher cost of the transgenic seeds, although farm profits, with or without modern biotechnology, vary a great deal from year to year and region to region. Clearly these economic considerations only hold for countries with economic structures similar to those of the US, but not to developing countries.

It is important to remember that a large number of transgenic crops are still in the development stage and will only come onto the market in a few years from now. They are likely to show benefits for the consumers and some may be of particular interest to farmers in tropical countries. Two rice varieties, with anticipated consumer benefits are those containing Vitamin A or an increased level of iron in the product, which were developed by Potrykus and Beyer (2000). Despite traditional preventative 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, one to two million die annually as a consequence of vitamin A-deficiency and 5,00,000 turn irreversibly blind every year. A bowl of 300 g of this cooked rice is thought to be 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, but are far from commercialization, for both scientific and political reasons.

For farmers in developing countries, the following GMOs may be of interest:

- virus-resistant cassava
- virus-resistant sweet potatoes
- virus-resistant papaya (already on the market in Hawaii)
- rice with an increased rate of photosynthesis, and, therefore, with a potential yield increase of up to 25 percent
- rice with increased salt tolerance
- diverse varieties that are partially aluminium-resistant and have the potential to grow in degraded tropical soils

- diverse crops that are more drought-resistant than the usual varieties.

All of these and many more crops have been proven to work, in principle, in laboratory and glasshouse trials. The practical benefits and risks of the crops need to be assayed in the field and their products scrutinized, like any other novel food. Several lines of transgenic farm animals have been produced, but none have been made commercial. Some lines are made for the pharmaceutical industry to produce drugs in their milk. Others may show improved resistance towards certain infections. Transgenic salmon that grow faster than normal have been developed and have roused considerable concern amongst ecologists. As pointed out by Reichhardt (2000), many environmental issues still need to be clarified in this context. However, it is clear that the transgenic crops that have been commercialized so far have not been seen to have done any harm to either the environment or consumers.

NATIVE BIODIVERSITY AND BIOTECHNOLOGY

Biodiversity in the wild has been massively reduced in the industrialized countries over a long period of time, in Europe, for example, over several millennia. Hardly any ecosystem is the same here as it was before humans started to clear forests and develop farming. When we look out of the window we see houses, roads and meadows, whilst three thousand years ago the area was covered in beech and oak forests. Even Europe's forests are more like manicured gardens than virgin forests, despite the mystical "naturalness" attributed to our forests, at least in Germanic countries. North America still has far more native, untouched ecosystems, either in the form of protected areas or in less hospitable regions like the North of Canada. Biodiversity has already diminished on a massive scale in the industrialized countries.

Yields of cereals have gone up very considerably in the last forty years. In the developing countries, this is primarily a result of the Green Revolution. However, the annual growth increases in cereal yields have slowed down from about 3 percent to 1 percent per year as shown by Pinstrup-Andersen *et al.* (2000). For the developing countries they were 2.8 percent in 1967 – 1982, 1.9 percent in 1982 – 1994 and only 1.2 percent in 1993 – 2020. These lower yield increases of recent years mean that productivity will probably not keep up with demand in the developing countries. The consequence on biodiversity is devastating and means that more land will be required for farming. This land will primarily come from areas with high native biodiversity, in particular the aforementioned tropical humid and dry forests or from marginal land. Whilst the green revolution has also had negative consequences, such as salination, excessive water use and soil degradation, the increased productivity it achieved allowed the maintenance of large tracts of native untouched land not used for farming.

Conway (1999) concludes that the single most promising way to avoid habitat destruction is to increase farm yields in a process that has been called the second green revolution. Several components will be required to increase productivity: better training and education of farmers (in particular women), more favorable economic and political climate, availability of microcredits, etc. In addition, technical contributions will also be necessary. One such contribution is improved seed, produced either by traditional crop breeding or by modern biotechnology. There will have to be more reliance on the latter, since traditional breeding seems to have reached a yield plateau. So agricultural biotechnology, which is viewed controversially in the public debate, may contribute markedly to conserve biodiversity by preventing the appropriation of native biodiversity-rich land for farming purposes. It should be noted, however, that this technology – like all others – is no panacea. Pinstup-Andersen and Cohen (2000) believe that each application needs to be studied carefully on a case-by-case basis, like any other new technology.

A valid concern is the possible effect of Bt-crops and similar plants on non-target insects. The Bt-crops contain a gene coding for an insecticidal protein originally produced by the soil bacterium *Bacillus thuringiensis*. They were developed to make the plants resistant to a particular highly damaging pest and have been quite successful in reducing pesticide input when infestation rates are high. In laboratory studies, Losey (1999) showed that the pollen from Bt-corn could kill larvae of the Monarch butterfly when a large amount of pollen was sprayed on the larvae's favorite food plant, milkweed. Subsequent field studies by Sears *et al.* (2001) showed that the Bt-corn caused little or no damage to the Monarch in real agricultural settings. This shows that the impact of transgenic crops on non-target organisms cannot be studied solely in the laboratory, but also requires farmland experimentation.

A more limited concern, that largely touches Northern Europe, is the conservation of native plants and animals, in particular, birds, in farmed areas. The birds' habitats are fields, hedges, roadsides and fallow land where they depend for food on insects and seeds produced by weeds in or near the crops. These seeds are particularly important in the winter months.

Computer models by Watkinson (2000) suggest that more intense weed control measures may lead to smaller amounts of seeds being available to birds. This effect seems plausible under certain conditions, but depends on weed management regimes rather than on the presence or absence of transgenic plants, and, therefore, is not an issue of biotechnology. Herbicide tolerant beets may allow farmers to tolerate weeds for a longer time and fight them only after sowing. This is made possible by a post-emergence herbicide treatment. More efficient weed management may also make it possible to set aside more land. If the lack of food results in a reduction in the bird population, this may lead to an increased number of harmful insects in the fields. It must be remembered that farming the land serves quite different purposes, particularly in Northern Europe. The primary goal is obviously the production of food, but secondary goals, such as conservation of biodiversity and giving city dwellers opportunities for outdoor activities, are also important. For the latter purpose, setting aside more farmland would be helpful. In order to do this, political will and financial incentives are a prerequisite.

AGRICULTURAL BIODIVERSITY AND BIOTECHNOLOGY

In addition to wild plants, old landraces might be threatened by transgenic crops. It should be remembered that vertical gene transfer by pollen has always occurred between different old landraces and between different new varieties of crops. Despite this, varieties of apples or cereals have been stable over many years and specific traits have not disappeared. Pollen has always flown.

What has become far more precise is the method of analysis. Thanks to gene probes and to GMOs, it has become much easier to follow gene flow, since one is no longer dependent on visible traits, but can follow a specific gene. Nevertheless, it is important to preserve landraces and native relatives of crops for their intrinsic value as well as for having starting material for future crop breeding.

Can newly introduced transgenic crops transfer genes vertically to native wild plants and thereby change important characteristics of the wild plants? Vertical gene transfer between cultivars and wild plants has always occurred within the limits of species, if the two types of plants were in close proximity and flowered at the same time. No new problems can be expected from transgenic plants, except if the gene transferred from the GMO to the wild plant significantly increased the fitness of the recipient. This seems rather unlikely *a priori*, but needs to be studied experimentally, as suggested by Ammann *et al.* (1999), both in the laboratory and the field. Herbicide resistance transfer from a herbicide tolerant, transgenic crop to a close relative can occur in the field, as has been shown for canola by Mikkelsen *et al.* (1996) in Denmark. However, this would be of major significance only if the recipient weed was controlled by this herbicide in this farm setting.

Small farmers in many developing countries use a remarkable number of races of many different crops. These are often well adapted to the local climate and topography, and are used to produce foods for different cultural purposes.

In the Andes region of South America, dozens of different varieties of potatoes are grown, often side-by-side on small plots. In Europe, different varieties of potatoes are used for the industrial production of chips, and for preparing dishes at home. Will the traditional races disappear when, and if, transgenic crops are introduced by farmers in developing countries? To judge from the past in Europe, the answer will be largely yes, not because of any biological hazard emanating from the GMOs, but because farmers need to produce their products and sell them economically.

CONCLUSION

Biotechnology can be a valuable tool for introducing novel (alien or non-alien) genes into underused crop traits and crop species. Furthermore, the development and introduction of GM crop varieties do not represent any greater risk to crop genetic diversity than the breeding programmes associated with conventional agriculture. After all, the overall performance of a plant and the quality and quantity of its product is the result of thousands of genes and the genetic background is almost always more important for the questions dealt with in this review than a single transgene.

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