Committee II
Agricultural Genetic Engineering
And Society

DRAFT--5/15/91
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BIODIVERSITY AND BIOTECHNOLOGY IN AGRICULTURE

by

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The Eighteenth International Conference on the Unity of the Sciences
Seoul, Korea August 23-26, 1991

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Final draft for the ICUS conference
August, 1991 in Seoul, South Korea

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Introduction

For several reasons, the rate of species extinctions has accelerated in the last decades. This rate is now much higher than the natural rate of new species evolution (MYERS, 1979, EHRLICH and EHRLICH 1981). In the course of the last 3.5 billion years a total of somewhere between 100 and 250 million species may have existed (MYERS, 1979). If we accept - just for this calculation - the idea of a constant

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rate of evolution it would be one new species every 1.5 to 3.5 years. The estimates about the existing number of species on earth vary widely, but many scientists believe that the 1.3 million species that have been descibed (WILSON, 1988) is only a small fraction of all. Based on his beetle counts in some tropical forest stands, ERWIN (1982) calculated a total of 30 million species. A recalculation by STORK (1988) leads to as many as 80 million species. The anticipated species loss during the next 20 year period will be probably as high as 1 million species (WOLF, 1985; LUGO, 1988; REID and MILLER, 1989). That means the extinction of one species in approximately every 10 minutes. This number is in sharp contrast to the rate of evolution one species every 1.5 to 3.5 years.

Being a long way from having described all species, we are much worse off in understanding how species act together in natural and managed ecosystems and what factors regulate their distribution and abundance (MACDONALD and SMITH 1990). In fact, the study of the distribution and abundance of organisms is the core of the ecological science (KREBS, 1978). Good examples for this lack in understanding are provided by biological control efforts. Even if careful studies suggest that an organism has the potential to be a successful control agent, the actual chance to realize its potential has been just 1 in 18 (PIMENTEL, 1986). In most cases the reasons for the failures remain unknown. (REGAL, 1986).

At the same time of alarming rates of species extinction, the science of biotechnology is emerging. Progress in molecular biology and related fields has created the option to insert specific DNA fragments from one species into the DNA of another species. Consequently, the engineered organism combines properties of different species. Some experts, like H.A. SCHNEIDERMANN (1986, cit. after S. HARLANDER 1989), expect that this "has the potential to change the technology paradigm of our present society far more than the industrial revolution, to transform the world's markeplaces and to enormously enhence the quality of human lives". Especially an agricultural revolution is likely to take place.

The revolutionary aspect of biotechnology in evolutionary terms is that there dont exist any phylogenetic barriers to gene transfer between species. Gene transfer even between different phyla, that can neither occur in nature nor be achieved by traditional breeding methods, have already been successful with biotechnology. For example, tobacco was manipulated to produce mammalian antibodies (HIATT et al, 1989).

The basic unit in taxonomy and also for important aspects of biological diversity is the species. After WILSON (1988, p.5) "species are regarded conceptually as a population or series of populations within which free gene flow occurs under natural conditions". A new species can evolve when a population (or a group of populations) is geographically separated from the others for a period of time. Then,

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due to genetical adaptation and random drift, the population can acquire enough differences to prevent interbreeding whith the populations it was separated from. When this is the case one species has evolved into two species. Based on the definition of a species, gene flow between species does not occur in nature.

If or not a transgenic organism should be considered as a new species cannot be answered generally. The aim of bioengineering is to produce organisms with properties that no other known species has. This makes them "functionally" new species. But if the organism under consideration can be regarded as a biological species will depend on different criteria. For example, if it will be able to reproduce under natural conditions, or if it will interbreed with other species. In fact, questions like these are not merely of academic interest but are crucial to assess some risks of releasing biologically engineered organisms into the environment and will be discussed later.

It seems completely impossible that engineered species can substitute for extinct species, because most - if not all- of the extinct species biology is unknown (EHRLICH and MOONEY 1983). Nevertheless, biotechnology and biodiversity are closely connected in different aspects, especially in the agricultural context. For example:

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- biotechnology depends on the existing species and their genetic variablity. Therefore, biotechnology has to have a basic interest in efforts to conserve biological diversity.

- the success of bioengineered organisms introduced to managed ecosystems, like agriculture or forestry, will depend on the diversity of these systems and their ecological processes.

- changes in the management practices in these ecosystems due to engineered organisms can possibly effect biodiversity.

In this paper I will discuss some of these relationships between agriculture and bioengineered organisms, especially engineered crops. I will outline some of the recent developments in agricultural biodiversity and try to assess some of the possible implications. My argument is that bioengineered crops can give a chance to a more environmentally sound agriculture. But this will only be the case, if other sustainable management practices are adopted as well.

Agriculture and biodiversity

Although 90% of the world food comes from just 15 plant and 8 animal species (MANGELSDORF, 1966; MYERS, 1979; WILSON 1988), there are thousands of other species used for food production throughout the world and many more may have the potential of

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being cultivated (CLAWSON, 1985; ALTIERI and MERRICK, 1987; ALTIERI et al., 1987). Some agricultural systems are particulary diverse, especially in the tropics. In Indonesia gardens, for example, more than 500 plant species were found (MICHON, 1983). In the Pacific Yap Islands farmers cultivate over 50 species of fruit trees in their gardens (FALANRUW, 1989).

In agroecosystems the crop represents just one part of a complex ecosystem. Even in temperate zones these ecosystems usually are highly diverse (TISCHLER, 1965). Consider milk production in a dairy farm with pastured cattle. The pasture vegetation may be composed by 10 to 50 species (KLAPP, 1965). The pasture soil harbours a far more diverse system in which hundreds of species may exist (TOPP, 1981). Another highly diverse system is connected to the cows rumen which harbours one of the most varied and dense microbial communities known in nature. More than 200 species of bacteria and more than 20 species of protozoa have been described, additional to several species of fungi (CZERKAWSKI, 1986). The breakdown of the cows manure is an additional complicated process in which many species are involved. (TOPP, 1981). More biological diversity is required if we allow the cows to feed on silage, hay, straw, pellets and so on. The important point is that each layer of complexity represents essential functions for the whole system of milk production. The pasture vegetation converts solar energy and nutrients into carbohydrates and other necessary food ingredients. Soil organisms stabilize the soil, break down organic material and

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activate plant nutrients. Rumen dwelling microorganisms transform plant material into usable nutrients for the cow. Also, the breakdown and decomposing of manure is essential for maintaining the pasture ecosystem. Only if all these subunits work the whole system can be maintained.

Problems with cows and pastures were demonstrated in Australia, after cattle were introduced approximately 200 years ago. Because there were no adapted organisms that could decompose cattle manure, large pasture areas became unproductive. In fact, the annual loss was approximately 400 m^2 per animal. In addition, the soil-nitrogen cycle was interrupted, leading to decreasing nutritional quality of the pasture vegetation. Also cattle parasites developed in the undecayed manure and became a severe problem (TOPP, 1981). After 1970, when several dung beetle species were introduced from Africa, they began to stabilize this system. Because the activity of each dung beetle species is restricted to both a specific time of the year and an area smaller than the one of the cattle, there will be at least 160 species neccessary to cover the hole grazing season and all relevant areas of Australia (TOPP, 1981).

If one views the pasture/cow complex, then a dairy farmer manages several hundred or thousand species just for milk production. Many more species, including microbes, herbs, trees, insects and other animals are needed if, in addition, the farmer hunts on the farmland, the family loves to watch birds from the kitchen window or

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appreciates wildlife in general. Thus, many more diverse species are needed to maintain a normal dairy farm than a large city zoo.

Many essential ecosystem processes, e. g. soil stabilization, mineralisation of organic matter etc. are carried out by rather small and inconspicuous species like microbes, insects and fungi. To a great extend "little things run the world" (WILSON, 1987). Despite their tremendous importance and diversity (PIMENTEL et al, submitted) our knowledge is relatively limited compared to what we know about the larger plants and animals (HOEKSTRA et al, 1991) and in conservation efforts they have been largely neglected (PIMENTEL et al, submitted).

On the other hand, plants can grow with no direct support from any other species at all. In some hypoponic plant cultures, for example, only the essential abiotic growth factors, like light, water and nutrients are provided. If carried out properly, hypoponically grown crops like tomatoes, are similar or even higher in yield and quality to field grown plants (COOPER, 1979). Similarly, in crop experiments in greenhouses or field plots no consideration of biological diversity in these settings is usually made. In fact, it seems that reports on agricultural yields have never been related to the total number of species in the agroecosystem. Hence, with crops it seems possible to reduce agricultural biodiversity without reducing productivity. Indeed, recent developments in agricultural practices seemingly try l 2 stae

to introduce the pauperized conditions of experimental settings into the real world.

It is interesting to note that even hypoponic plant cultures are indeed dependent on the acivity of many species. Many of the factors that we like to call "abiotic" like temperature, oxygen and precipitation are in fact abiotic only at a small spatial and temporal scale. As soon as we consider a large, for example global scale it becomes clear that these factors are greatly modified by the vegetation. In fact, the atmospheric gas composition is largely the product of photosynthetic activity. Therefore all climatic factors have a strong component that is based on biological activity.

Biological diversity in some agroecosystems is declining at an alarming rate. In West-Germany for example, the agricultural practices are considered to be the most important factors of species decline in the last decades (SUKOPP, 1981). This trend is correlated to increasing yields and decreasing numbers of farms (RSU, 1985). Possible environmental impacts by the introduction of bioengineered crops can be assessed only, if recent developments in modern agriculture are understood and their implications for agroecosystems are taken into account.

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Species loss in agricultural ecosystems

There may be a relationship between increasing rates of loss of species and the development of bioengineering. It appears that the release of engineered organisms is most likely to occur in intensely managed ecosystems which have suffered a high loss of biological diversity (PIMENTEL et al, submitted). However, in conservation efforts most attention has been paid to largely pristine ecosystems, like tropical rainforests and others (REID and MILLER, 1989). Even in highly populated countries, like West-Germany, conservation efforts are mainly connected to semi-natural habitats (KAULE, 1986). Until recently, it has largely remained unnoticed that an enormous loss of diversity is taking place in some managed ecosysytems as well, like agriculture or forestry. In West-Germany for example, virtually no ecosystem has remained unaltered by man. Today most of the approximately total of 30,000 species live outside the protected areas in human managed ecosystems. It is in these areas where biological diversity is declining most rapidly, 30 to 50% of all occurring plant and animal species are considered to be on the brink of extinction in these areas (RSU, 1985).

Due to a wide array of reasons, agricultural practices have changed drastically in the course of the last decades. In many aspects, this has caused a loss of diversity. In a single arable field, the diversity of crop species in a rotation often has declined. Until recently, crop rotation was the most powerful means to maintain soil quality and

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suppress weeds, deseases and insect pests. Careful management of soil organic matter and soil structure sometimes required a crop rotation of seven years duration (GEISLER, 1988). Today, weed-, pest- and soil-management strategies have become more and more the task of herbicide, fungicide, insecticide and fertilizer input than rotation. This resulted in a reduction of crop species and varieties, leaving almost only the most profitable crops in the rotation. Some modern rotations constitute of just two or three crops, or even just one in monoculture. These rotations are based on economical rather than biological considerations and can be maintained only as long as the input of agrochemicals continue to achieve high enough yields and only if there are no intolerable side effects (GEISLER, 1988). Some monocultures, like corn in some areas of the US, have more detrimental effects on soil erosion, water runoff and pest populations than a rotation with soybeans (PIMENTEL et al, 1991).

Related to changes in reduced crop rotations, increased pesticide and fertilizer applications, the wild flora here lost many species. Flax (*Linum usitatissimum*) fields for example harboured some specific weeds that were closely associated with this crop. At least five plant species disappeared with the discontinuation of flax cultivation in Germany (RSU, 1985). For nearly every plant species is host to specific insect species (PIMENTEL, 1988), many more species go extinct when a plant species disappears. Alone with the weed species *Convolvulus vulgaris* 30 specialized herbivores are associated. One of these insect species is host for 13 parasitoid species (LEIN, 1982).

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Herbicides also cause species extinctions. CALLAUCH (1981) calculated that herbicides are the most important factor for 68% of the declining plant species. Another threat to the weed diversity is that soil conditions have changed in many fields. Dry sites have become irrigated, wet sites have become drained, nutrient poor sites have become fertilized (SUKOPP et al. 1978). For much of the established weed flora of these sites the environmental conditions changed so drastically, that many species are no longer able to survive. The most troublesome weeds today are those that are hardest to control chemically (KOCH & HURLE, 1978).

The decline of biological diversity in agricultural landscapes is in part due to changes on the field level. Larger machinery requires larger fields. These changes have lead to the destruction of seminatural habitats between fields like hedges, ridges, ponds etc. This has been a major reason for species disappearing in agriculture (SUKOPP, 1981). Also, fertilization, soil erosion and pesticide application affect areas adjacent to the target area (PIMENTEL and LEVITAN, 1986). This can alter the environmental conditions and cause extinctions.

Agriculture as a part of other systems

Species loss in agriculture has been negatively correlated to the increase in crop yields, at least in West-Germany (RSU, 1985). Nevertheless, there are limits to this development given by the

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imperative of longterm productivity of agriculture and the necessary functions of ecosystem processes. Therefore many species are needed, but actual numbers are completely unknown. More limits to species decline are set by other systems to which agriculture belongs. In the geophysical water cycle, for example, the quality of drinking water in some areas is affected by the use of fertilizers and pesticides (BOUWER and BOWMAN, 1989). The relationship is connected to changes in agricultural management practices. Similary, programs to preserve biological diversity in a country have to include agricultural land use and management practices to be successful (RSU, 1985; ALTIERI et al, 1987; STACHOW, 1988). Social demands to nature conservation therefore are directly related to agricultural technologies and have the potential to influence the progress or set limits to agricultural development. This is especially true in areas where managed ecosystems dominate. Some countries, like Sweden, Danmark and The Netherlands, have developed plans to reduce the amount of pesticides used in agriculture by 50% in the next years (PIMENTEL et al., 1991). Also for the USA, a reduction of pesticide use by a similar percentage seems possible (PIMENTEL et al, 1991). This could be accomplished by replacing some pesticides by cultural, biological and environmental control methods and adopting integrated pest management (IPM) strategies.

When the agriculture causes severe environmental problems, like species decline, groundwater pollution, erosion, residuals in food etc. it is likely that the social and political pressure on the agriculture to

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change will increase. This is especially true in countries like the EC nations or the USA, where the agricultural productivity exceeds the demand, because the present type of high input technology does not seem neccessary to secure sufficient food production. For example, the pesticide use in some US crops can be reduced by much more than 50% without reducing yields (PIMENTEL et al, 1991).

Time delay in environmental problems

High levels of nitrogen have been found in ground water especially in areas with high input of nitrogen fertilizer and permeable soils (POWER and SCHEPERS, 1989; STREBEL et al, 1989). Pesticide residues are a similar problem (HALLBERG, 1989; LEISTRA and BOESTREN, 1989). It is worth noting, that these negative side effects of high input agriculture often became obvious years after their introduction. In environmental science, a time delay between the measurements that cause problems and their actual appearance is quite common (TIEDJE et al, 1989). This makes it very difficult to demonstrate factor by factor relationships in repeatable experiments. This has been the standard requirement for scientific evidence of a cause-effect relationship. Another problem with a time delay is that an adverse effect cannot be slowed down easily or stopped even if the causative factors are halted. So, even if we stop completely the application of nitrogen fertilization and pesticide application to protect ground water contamination, the actual amount of pollutants

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in the water can stay the same for some time or even rise before it actually declines (HALLBERG, 1989). However, most of these physico-chemical problems are manageable in principle. Given a large enough amount of time a critical situation can be reduced.

A different situation exist with biological hazards like the release of pest organisms. For example, a large number of species has become established in areas where they never occured before. In the US alone approximately 1500 insect species have been introduced from Europe, Asia and other areas, and are now part of the North-American fauna (PIMENTEL et al, 1989). Many of these species have become serious pests in agriculture and forestry (SAILER, 1978). This is an ongoing process and no decline in the rate of introductions have occured. For example, SAILER (1983) calculates that 11 species of arthropods successfully invade the US each year.

Invasion is a threat to biological diversity in many areas of the world (MOONEY and DRAKE, 1986). Some islands are particularly susceptible. For example, over 50% of the New Zealand flora is non-native (MOONEY and DRAKE, 1990). Only in very few cases has it been possible to exterminate an introduced pest organism. For many introduced species, especially small ones like insects, microorganisms and viruses it is very difficult or impossible to undo the introduction (COLWELL et al, 1985). The main reasons for that are connected to basic properties of living organisms and ecosytems. Members of a species reproduce, some disperse actively and they show genetical

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variance so that they are able to adapt to specific conditions. Ecosystems obviously have often more niches than species, which means that they are rarely saturated with species and therefore invadable (TIEDJE et al, 1989). Even in many relatively undisturbed nature reserves high numbers of introduced invasive species can be found (USHER, 1988).

Bioengineered crops: some general concerns

The techniques of gene transfer between species represent powerful tools in plant breeding. It is possible that entirely new properties can be established in crop species. Areas of intense biotechnological crop research include pest resistance, pest tolerance, herbicide resistance, nitrogen fixing ablility, salt tolerance and drought tolerance (GASSER and FRALEY, 1989; OKON and HADAR, 1987). Successful bioengineering is supposed to improve farming practices like pest management, to reduce the amount of fertilizer and to broaden the environmental conditions suitable for planting a specific crop species. In addition, a set of new crop properties is hoped to be achieved with biotechnology by the food processing industry. For example, increased solids content in engineered tomatoes would help to reduce the amout of water that has to be removed during processing (LEWIS, 1986), or a decreased level of saturated fatty acids in engineered rape would enhence the nutritional quality (KNAUF, 1987).

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From an agroecological point of view, some effects of the introduction of bioengineered crops deserve special attention. First, the time requirements to develop a new line may decline. With traditional plant breeding methods it takes 8 to 10 years on the average to produce a new grain crop variety (M. SORRELLS, pers communication). Biotechnology not only can shorten this period, but a transgenic crop variety can be expected to differ more from predecessor varieties than a variety bred by traditional means. This will result in an accelerated rate of change in agricultural technology. The effect can significantly increase the delay between agricultural production and ecological understanding and evaluation of the altered system. Undesirable side effects might be detected a long time later. Given the experiences with the environmental impact of current agriculture, like groundwater contamination, pesticide residues, some forms of soil erosion and species decline, an inreasing time gap seems to be problematical.

Not only the agricultural technology will probably continue to change fast with transgenic crop varieties, but also the economic constrains in the agricultural markets. Increased productivity causes a decline in number of small farms. For example, an OTA study (OTA, 1986) predicts that " approx. 1 million farms will disappear between now and the year 2000, mostly moderate-size to small farms" in the US, due to the increase in agricultural productivity. Forgetting the social problems associated with an accelerated rate of farm bankruptcies,

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increasing farm size associated with reduced biological diversity. For example, KNAUER and STACHOW (1986) compared two adjacent areas of a landscape in north Germany. One was dominated by medium-sized family farms, the other by large farms. 10 different crops were grown in the small farm area. The average field size there was 4.5 ha. In the other area only five crops were cultivated on much larger (average 29.9 ha) fields. Also the diversity and density of small seminatural habitats, like hedges, was much higher in the first area.

The second ecological consideration addresses the relationship between the environmental conditions and the selection of a set of livestock or crop varieties on a specific site. In previous times factors like soil conditions, climate, occurence of pests and weeds dictated more or less which crops could be grown and which production system should be implemented. Then, whith the introduction of synthetic pesticides and fertilizers, for example, the crop became more independent of the site where it is grown, because some of the limiting factors, like the nutrient availability and the pest status could be controlled. These options have resulted in uniformity of agricultural production methods and consequently a decrease in diversity. There is good evidence, that the increasing uniformity in varieties, production methods and rotations contributed largely to new environmental impact, for example the developement of new pest problems (BARRETT, 1981). Genetic uniformity in corn was the main factor why Race T of the Southern corn leaf blight

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Helmithosporium maydis could overcome the resistance of its corn host in 1970 and caused devastating losses (THURSTON, 1973; NELSON et al., 1970). The boll weevil *Anthonomus grandis* has became a key pest of cotton in the Americas only in the last 90 years despite the fact that cotton had been grown in that area for several centuries. The increase in harmfulness is mainly due to increasing uniformity: currently prevailing are extensive monocultures with a high genetically uniformity instead of previous effective and continuous cropping and consistent and varied preventive cultural control practices (FISHER, 1989).

The important point is that the environmental conditions in a site are becoming less important in determining basic decisions, like which crop to grow, which technology to choose and which rotation to adopt.

Bioengineering has raised hopes to develop crops with ideal properties for the processing industry and the consumer as well. If this holds to be true and crop properties like taste, appearance and nutritional value can be changed easily and quickly with bioengineering, this trend can increase dramatically. Major decisions about agricultural practices are then being made indirectly by mostly urban based groups with much concern about the crop quality itself and less concern and understanding about the longterm productivity and sustainability of agroecosystems. This would be remarkebly different from the present situation. In extreme, the task of agriculture changes from producing environmentally adapted crop plants to multiplying "custom-designed plants". This can well lead to an increase in diversity regarding crop species and varieties (HANSEN et al. 1986; BUSCH, 1990). But the important question is if this will translate to an increase of biological diversity in the other parts of agroecosystems as well.

Assessing ecological impacts of bioengineered crops

Herbicide resistant crops

Some environmental problems of current agriculture are supposed to be reduced with transgenic crops. Actually, this argument is often being used to promote biotechnology. For example, SCHULZ et al. (1990), in reviewing the development of herbicide resistant crops, write that "the cultivation of herbicide-resistant plants is advantageous for the environment since reduced amounts of herbicides will be used and older products will be substituted by more favorable ones" (p. 1). They predict "that the economic and ecological advantages will far outweight the hypothetical disadvantages" (p. 11).

Nevertheless, the breeding for herbicide resistance does *not* aim at reducing herbicide applications. This is just considered as a possible side effect. Herbicide resistant crops are supposed to enable better weed control - not less pesticides use. We can assume also, with the

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same degree of justification, that herbicide applications will increase. This is because weed control then can be achieved completely by herbicides while traditional non-chemical methods, like crop rotation and intercropping, become superfluous. Also, herbicide resistant crops can grow on herbicide contamined soil that restricts the planting of non-resistant crops. So, possibly less attention has to be paid to pesticide residues in the soil. If minimizing herbicide applications would be the target of crop-bioengineering a direct approach seems to be more appropriate than via herbicide resistance. A direct way to achieve this goal is to enhence the crop competitivness against weeds. If crops were less susceptible to light, nutrient or water competition of weeds, the economic threshold of herbicide use would be higher and as a logical consequence the herbicide use would be less.

Crop species and varieties differ significantly in their ability to withstand weed competition. Some crops, like rye are particulary good weed suppressors. The quickness of germination and leaf development, the leaf shape and form, the extent and quality of the root system are some of the plant properties that determine the competitional success (HOLZNER and NUMATA, 1982). Introducing new properties for weed competition with bioengineering seems to be a much more environmental sound approach to reduce herbicide applications.

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An additional problem with herbicide-tolerant crops is the possible gene transfer to related species via pollen. This has been demonstrated in some cases (ELLSTRAND,1988; COLWELL et al, 1985; HAUPTLI et al, 1985). Even when the chance is very small this represents a major risk to produce herbicide resistant weeds unintentionally. Gene transfer via pollen may be possible as well for genes that enhance the competition against weeds. The important difference in risk assessment is that herbicide-resistance represents an absolute property. Either a plant is resistant or it is not. If a weed becomes herbicide resistant, a weed control system which is based on this herbicide, doesn't work any longer. On the other hand, competitive properties are relative. Even if gene transfer occures to weeds, the cropping system is likely to function.

In essence, the introduction of herbicide resistant crops reduces the weed management to just two steps: planting the resistant crop and applying the appropriate herbicide (both probably available from the same chemical company). Only a few resistance genes are needed for the engineering of herbicide resistance. The other approach tries to shift the competitional balance between crops and weeds towards the crops, thus, enabeling the farmer to practice additional non-chemical weed control methods.

Nitrogen-fixing crops

Similar considerations apply to the engineering of nitrogen-fixing crops. If, for example, wheat or corn would have the same system of

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nitrogen fixing as legumes, no additional nitrogen fertilizer would have to be applied to these crops. This could save enormous amounts of energy (25%) and money (30%) (PIMENTEL, pers. communication). But with introducing nitrogen fixing abilities to crops, another serious environmental problem connected to nitrogen fertilization is *not* being addressed, that is leaching. Nitrate leaching is a major environmental problem in some areas of intensive agricultural production, especially for groundwater quality. There is a correlation between land-use and nitrate concentrations in the groundwater. In West-German waterworks, for example, the N-amount in the drinking water is lowest in forest-dominated areas and highest in agricultural areas (GEISLER, 1988). The general trend is a continous increase in nitrate, in some agricultural areas at a rate of 3 mg per year (RSU, 1985).

Many nitrogen fixing crops like legumes fix atmospheric nitrogen in variable amounts. Soybeans, for example, fix 0 to 314 kg N per ha, depending on factors like management, soil conditions and water availability (NRC, 1989). Often nitrogen leaching from legumes is higher than from any other group of crops. (GEISLER, 1972). Simply engineering for nitrogen fixing ability in more crop species will probably result in even higher leaching and groundwater contamination, at least in some areas.

N-leaching can be controlled, at least in part, by management practices. Especially controlled fertilization and permanent

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vegetation cover are important to minimize losses. In cropping systems the planting of catch crops can lower the amount of leaching drastically. STEFFENS and VETTER (1984) found in a comparison that the leached water amount with catch crops was reduced by 20%, the nitrate concentration by 50% and the total nitrogen by 50 to 70%. Also minimal tillage can contribute to reduced leaching. Crop rotation is particulary important for a balanced nitrogen system in the soil (STREBEL et al, 1989).

Introduction of N-fixing crops, other than legumes, can be a valuable contribution to save energy and labor. But the environmental impact due to leaching can be severe. Only with careful management and adoption of environmental sound practices, like catch crops, intercropping and crop rotation an increase in nitrate contamination seems to be avoidable.

Pest resistant crops

During the last 100 million years of coevolution of higher plants and insects many coadaptations have been developed, for example plants exhibit many physical and chemical defences to reduce damage by insects. Compared to wild plants crops generally have a low insect resistance (BOULTER et al, 1990). Bioengeneering for pest resistance aims to transfer resistance mechanisms from a resistant wild plant to a crop that is susceptible to specific insects. Similarly, some microorganisms produce toxic substances for insects. For example, the bacterium *Bacillus thuringiensis* ("Bt") has been used as an insecticide mainly against lepidopteran larvae for over 20 years (DULMAGE, 1981).

In 1987 the first reports appeared on successfully engineered plants (tobacco and tomato) with the Bt toxin produced endogenously (VAECK et al, 1987; FISCHHOFF et al, 1987; BARTON et al, 1987). As anticipated, on the transgenic plants many of the applied larvae died, whereas the control plants were highly damaged. A similar success was achieved with an insecticidal trypsin inhibitor (CpTI) that was transfered from cowpeas to tobacco (BOULTER et al, 1990).

Taking into account the rapid progress in the field of bioengineering and the very large pool of suitable genes it seems possible to tailor the resistance to many pest situations. Indeed, many problems connected to the current use of pesticides could be mitigated with endogenous synthesis of insecticidal compounds.

The major problem with insecicidal components, regardless wheather applied as a spray or produced by transgenic plants, is the development of resistance by the pest. Since 1914, when a report on resistance of the San Jose scale to lime sulphur was published (MELANDER, 1914), the number has increased at a near exponential rate to now probably more than 504 species of insects and mites (GEORGHIOU, 1990). At least one pest species, the Indianmeal moth

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Plodia interpunctella (Hübner), has become resistant to the Bt-toxin (MCGAUGHEY and BEEMAN, 1988)

Important factors in determining the development of resistance are the genetic plasticity of the species, the population size, and the selection pressure. Whereas the genetic plasticity cannot be easily manipulated, the pest population size as well as the selection pressure are important segments in resistance management strategies (GOULD, 1988). A bioengineered crop that constantly expresses insecticidal substances can produce a more severe selection pressure to develop resistance than sporadically applied pesticides, because of the constant exposure to the pest (ROUSH, 1991). Equally, the area planted with the same kind of pest resistant crop will influence the pressure on a larger spatial scale.(BARRETT, 1981) The smaller the fraction of the pest population that can feed on non toxic plants or plant parts the greater the selection pressure to adapt to this toxin.

To minimize the risk, several strategies have been suggested (ROUSH, 1991), including the restriction of the toxin expression to the most susceptible plant parts or growth stages as well as the planting of mixtures of resistant and nonresistant crop plants. Also, immigration of pests that can develop on non resistant plants can slow down the risk considerably. This can be achieved with alternative host plants, regardless wheather these are different crops, varieties or wild

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plants. Consequently, a vegetational diversity is desirable to manage the resistance problem.

Equally important, the selection pressure towards pesticide resistance in pests is affected by the proportion of the pest population that is exposed to the insecticide and the pest population size itself. The smaller this is, the better. So, all non-chemical control methods, like crop rotations and biological control, remain important and should be employed to the greatest possible extent. For example, enhencing the natural enemy species like predators and parasitoids, may require additional food sources, like nectar or alternative insect hosts, shelter and overwintering sites. This is most likely to be sufficient in a diverse agricultural landscape with many different crops and also considerable amounts of undisturbed, seminatural habitats.

Thus, the prospect of pest resistant crops via biotechnology offers a great chance to reduce the environmental problems related to chemical pest control. But this new technology is to be considered not as an alternative to existing pest control strategies, but as a very powerful member in the set of all non-chemical control means. A long term success is most likely if the biological, cultural and biotechnological methods can be integrated. This could mean a diverse set of control options, based on a biologically diverse agroecosystem.

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