Global Dialogue EXPO 2000
The Role of the Village in the 21st Century: Crops, Jobs and Livelihood
15 - 17 August 2000, Hanover, Germany

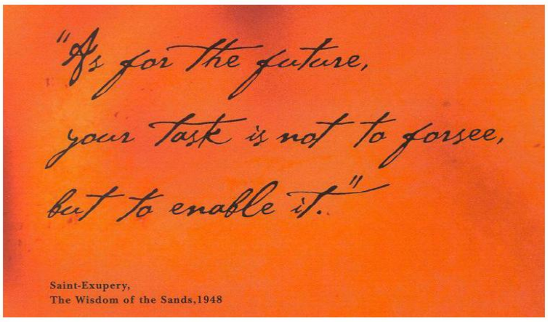
Future of Agriculture

Dr. Manfred Kern
Aventis CropScience, 2000
Bayer CropScience, 2003

Present address:
agriEXCELLENCE GmbH
Traminerweg 8, D-55296 Lörzweiler
E-mail: info@agriexcellence.de
Phone: +49 6138 98 12 190
Mobile: +49 173 214 3961
Fax: +49 6138 98 12 189

Future developments and break-throughs are hard to predict. They are even harder to produce to order. Nevertheless it is reasonable enough to think of a shopping list of what we want and what we need, and of what we can and, ultimately, should do. When trying to answer these questions the following statement given by Saint-Exupéry in "The wisdom of the sands" (1948) should be kept in mind: *"As for the future, your task is not to foresee, but to enable it."*

The Wisdom of the Sands, *Saint-Exupery*, 1948



Why and how can we improve and increase the carrying capacity of the earth?

These are key questions at the beginning of the third millennium.

Agriculture is the way people have increased the carrying capacity of the earth for humans. Technology was an integral part of agriculture and technological changes were driving the shape of agriculture. This will remain a key factor for agriculture in the future.

For more than 10,000 years imagination and use of agrotechnologies, (from wooden plow, water-wheel, ridge drill, improved seeds, new horticultural crops, horse-drawn vehicles, dung, fertilizers, hybrid seeds, plant protection agents, tractors and combine harvesters to genetic modified plants, and satellite-controlled tillage and harvest) have contributed to the availability of food for 6 billion people.

Is food security of global concern?

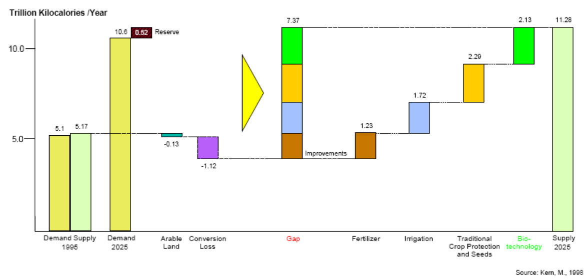
Today, during the two and a half hours taken up by our session Science in Dialogue "Future of Agriculture", the world population will have increased by another 17.000 people, most of them in developing countries.
There is no escaping the fact that "food and safeguarding of food supplies" is a topic which will continue to increase in importance. The number of conferences held on the subject has increased threefold since 1994, with 400 to 500 per year and the tendency pointing upwards.

The central question is: **How can we feed the future world population in a sustainable way and in keeping with human dignity?**

Let us take a look at the factors "requirements" and "consumption" up to 2025 (2050). Round about 1850 the number of people on this planet was approximately 1 billion, and during 1999 the number reached 6 billion. Mean estimates indicate that by 2025 the world population will have risen to more than 8 billion. However, this numerical increase is not the main problem for future world food supplies and the safeguarding of these supplies; a much greater impact will be had by rapid economic growth in the key regions of our planet. By 2050 the world economy is projected to be five times larger than it is today (Heaton, G. et al., 1991).

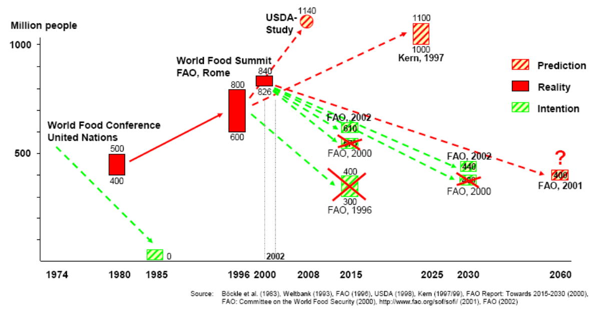
This economic development will very quickly alter world eating habits and increase total food consumption – first of all regionally, and then throughout the world.
A look at the increases in calorie consumption will reveal significant regional differences.
Consumption today in the Western world is around 3.400 kilo calories per head and day. The increase here over the next 25 years is hardly worth mentioning: 3.470. At the same time the average global calorie consumption rate will increase from 2.700 to 3.000. Here is where the great challenge lies. To make this clear, let us take Asia as a whole – China included – where the calorie consumption will rise from 2.400 kilo calories per head and day to 2.880 by the year 2025. This means that about 50 percent of the world population are moving over from low calorie consumption to a more nutritious dietary level, through still not up to Western standards.
And if we now look at the food requirements and food production of the world as a whole, we will find that we have a slight "surplus". The word "surplus" suggests that we already have more than enough. But this is not so**:** at the moment only 0.26 percent more food is being produced than is actually consumed.

Innovations in Agro-Technologies are Key-Factors to Satisfy Future Food Demand



And this without even allowing for the fact that we are still a long way from eliminating the hunger of 0.84 to 1.2 billion people in the world today. A prediction of the USDA (1998) shows that the number of malnourished will rise from current level of 840 million people to 1140 million in 2007. Worldwide, 1.3 billion people live on less than US $ 1 per day and the majority of them are in agriculture.

Global Malnutrition: Predictions and Reality, 1974 - 2030



"Hunger is the central problem of our time", wrote Greiling, W. in 1954*. "Hunger highlights the mistakes of our time and our world. Hunger on earth (600 million people) is a very special tragedy. It is not unavoidable. The means to overcome hunger are available, but they are not used. The rest of the world could help easily. But the rest of the world is doing more or less nothing."*
Hunger is not just a problem of distribution. Safeguarding world food supply would not be feasible without efficient use of available agro-technologies and without consequent realization of new agrotechnologies over the long term (Qaim, M. and Virchow, D., 1999).

Our first priority must be to create the technical basis for producing sufficient calories and energy-rich food to meet human needs throughout the world. We must bear in mind that over the next thirty to fifty years world food requirements will more than double, and this will make it necessary to double – and even treble – agricultural production and supplies. At the same time, we will have to compensate for reduced farmland areas, water shortages and the switch from plant-based to meat-based diets. This not only requires a different sort of *"green revolution"*, it also requires a *"blue revolution"* in terms of water conservation and sustainable use.

In the next thirty years we will have to produce more food worldwide than over the whole of the last 10,000 years. And we will have to do all this in a sustainable and environmentally compatible way. "*Meeting the needs of the present without compromising the ability of future generations to meet their own needs*" is our guideline for sustainable development written in the Brundtland commission report in 1987 and prioritized in Agenda 21: Programme of action for sustainable development in Rio de Janeiro, 1992. In the developing world, as elsewhere, food security requires access by all people at all times to enough food for an active healthy life. To ensure such access to food in the developing world requires sustainable agricultural development on both high and low potential lands.

Take the situation 10,000 years ago when some neolithic woman noticed that delicious grass seeds could be collected and covered in soil, and that she could come back later to more easily harvest the concentrated numbers of nutritious seeds. This new knowledge greatly increased the capacity of the ecosystem to feed more people than hunting and gathering could support. The breakthrough was not the seeds – human beings had been gathering and eating grass seeds for ten of thousands of years – rather, it was the idea that they could deliberately increased by planting them (Bailey, R., 2000).

Developments in crop cultivation and the revolutionary changes they brought about both in the composition of human diet and in the socio-economic system were put into practice for the first time 8000 years ago in South-West Africa, and soon afterwards in Egypt, India and China. Even in those times there were winners, in the sense of active, risk-taking knowledge-users, and "losers", in the sense of non-users - due mostly to inexperience and ultimately to virtually non-existent methods of communication.

This was followed at a later date by the domestication of hoofed animals, which brought about revolutionary changes in transport technology. Trade became possible, resulting in ever-increasing liberation from emergency and deficiency situations and in greater freedom of movement for an ever-increasing number of people. Agriculture became the basis of urban civilizations which gave rise to architecture, sciences, arts and technologies.

All of us will be under an obligation to answer the following questions:

What must we do, what must we try to achieve, what actions must we take, and what constructive changes must we make in order to keep a sound balance between world food security and an intact environment?

For this reason I would like to draw your attention to the Rio conference of 1992 on *Sustainable Development*, Agenda 21, Chapter 16, on the subject of biotechnology. Chapter 16 expressly propagates gene technology. Although it refers only to biotechnology, the wording in this context is invariably used in the sense of gene technology. *"Biotechnology is the integration of the new technologies emerging from modern biotechnology with the well established approaches of traditional biotechnology. Biotechnology, an emerging knowledge-intensive field, is a set of enabling techniques for bringing about specific man-made changes in deoxyribonucleic acid (DNA) or genetic material, in plants, animals and microbial systems, leading to useful products and technologies."*

In view of tasks confronting a sustainable future agriculture, genetic engineering combined with improvements in conventional production technologies will make a decisive contribution to the production of more food and raw materials on a sustainable basis and on already farming areas.
We have to be and we have to become cleverer about re-arranging material and utilizing resources.

Sustainable development means continuous innovations, improvements and utilization of environmentally friendly technologies with aim of reducing environmental impact and consumption of resources.
Improving sustainable agriculture means dematerialization and re-arrangement of resources or with other words: "Do more with less!"

Why is the preservation of biodiversity a common concern of mankind?

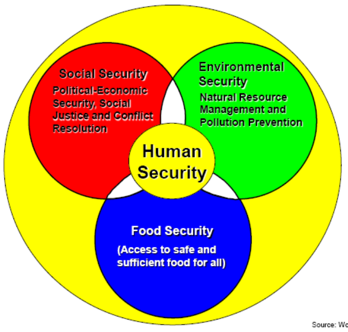
"The preservation of biodiversity is a common concern for mankind" (Convention on Biological Diversity, Rio de Janeiro, 1992). The Rio de Janeiro convention on Biological Diversity was a milestone on the road to sustainable conservation of the earth's genetic resources. The preservation of biodiversity is an essential pre requisite for the future development of the earth as a viable habitat. It is therefore an objective worth pursuing in its own right. New insights into processes and structures, and genes of animals and plants, will also help us to find new ways of combating diseases, safeguarding the food supply of the world's growing population and protecting the environment. The preservation and sustainable utilization of the diversity of species is of vital importance for the interest of all mankind, for the countries, which supply these recourses and, last but not least, for the health and food industries.

Let me give you an example to illustrate the importance of preservation: One single Peruvian peasant who cuts down rain forest to feed his family and then moves on from one patch to the next as soon as the nutrients in the soil have been used up, will destroy trees and insects of more species than are native to the whole of Europe. And he will go on felling trees as long as he cannot earn his living in any other way.

A World Wide Fund for Nature (WWF) report claimed that more tropical forest burned around the world in 1997 than at any other time in recorded history. In the words of WWF Director General Claude Martin, *"This is not just an emergency, it is a planetary disaster."* The following year, when the drought resumed, many of the old fires reignited from unquenched embers in smoldering peat bogs, and hundreds of new fires were lit, as usual, by loggers and subsistence farmers. Most forests are felled or burned to

provide timber, to create farmland, and to make room for urban expansion. Such processes guarantee the demise of many thousands of species every year.
"Biodiversity can be rescued from the grindstone of poverty only if we can find new potential uses for already cleared land and for the remaining intact areas. We must look for new methods to make better use of the yield potential natural habitats – without involving their destruction – and to encourage the invisible hand of the free market economy to grow a green thumb. The search has already started", said by E.O. Wilson (1997).
Protection of global biodiversity areas, conservation of biodiversity on arable land and safeguarding of the biodiversity potential of crop plant species are key areas of biodiversity, sustainable agriculture, sustainable development and, ultimately, of a sustainable socio-economy.
It is obvious that human impact on the natural environment depends fundamentally on an interaction between population, economics and technology.

Sustainable Human Development



Source: World Resources Institute, 2000

Carved in stone in the entrance hall of the Museum of Natural History in New York are the following wise words of Theodore Roosevelt (1858-1919):
"Nature: There is a delight in the hardy life of the open. There are no words that can tell the hidden spirit of the wilderness that can reveal its mystery, its melancholy and its charm.
The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased and not impaired in value.
Conservation means development as much as it does protection."

What are the implications of urbanization and the graying of populations?

Agriculture was once the place where the vast majority of human beings worked and lived, but currently, 55 percent of the world's population is not engaged in agriculture.
"5 Dec. 2006, 6 min. past midnight, the human being will be primarily an urban animal" was scheduled by Fazal Anwar (UN-Program Asia Pacific 2000, in Naisbitt, J., 1995).
Within the next 6 years, more than half of the world's population, an estimated 3.3 billion, will be living in urban areas. By 2025, it will be almost two-thirds of the global population.

At the present time there is no city in any of the poor countries in which public investments in new housing, efficient waste disposal, highways, transportation or other infrastructural basics of governmental services kept pace with the urban growth rate of the past three decades, and there is no prospect of an improvement in the foreseeable future.

Some one billion people already live cooped up in slums; at least 220 million urban dwellers lack access to clean drinking water (Agenda 21); more than 420 million do not have access to the simplest latrines and other bare essentials of a decent standard of living. This has notable consequences for the quality of life and physical security of city dwellers.
As it also does for food security: Urban populations are not able to feed themselves by subsistence food production, and their eating patterns differ from those of rural folk. The amount of high-value, transportable and storable grain such as rice and wheat, animal protein, and vegetables in their diets is higher, with a corresponding decrease in the proportion of traditional foodstuffs.

How can we feed the citizens?

This is the title of book written by C.R.W. Spedding (1996), which is well worth reading. The practical answer can only be given by villagers related to agriculture and primary food production.
However, among many policy makers and citizens "village" is still associated with backwardness, inflexible traditions and an attitude of hostility towards technological innovations, summarized in the announcement of our symposium "The Role of the Village in the 21st Century: Crops, Jobs and Livelihood."

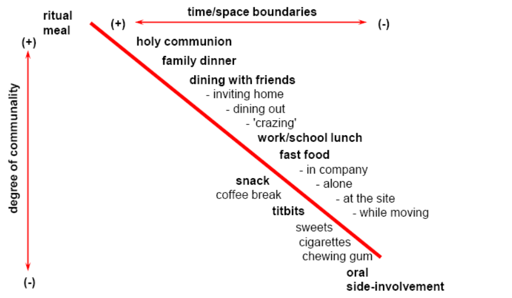
Many citizens are unfamiliar with agricultural production systems, whether in their own region or in the developing countries. What they know about them is patchy or of a "virtual" nature. They expect to have permanent access to, and free choice of, cheap, healthy and varied food at all times, 24 hours a day. This is not likely to be the case in many of the developing countries or least developed countries.

In general *"The rich get richer, the poor have children, and the old get older."* (www.an.af.mil/an/2025/monographs/.../a-f-b.ht) documented in an Airforce 2025 monograph.

A calculation made by Weiner, F. (2000) concerning the cost of raising children and the cost of caring for the old, sounds cynical, but it is understandable: *"It takes a village to raise a child, but it takes a village, three doctors, five consulting specialists, and six hospital beds to care for an old man."*
Nowadays, for example, there are 82 million people living in Germany, in 2050 there will be only 70 million. For every 100 persons of working age there are about 40 persons older than 60 years. In fifty years, according to a forecast from the German Office of Statistics (July 2000), this ratio will be 100 to 80, i.e. twice as high.
With the overall demographic shift, populations are aging.
This applies especially to the highly industrialized countries, but will in future also apply to developing countries, since the median age of the population of about 26 years to today will increase over the next 50 years at global level to over 44 years (Schartz, P. and Leyden, P., 1998). Global life expectancy has grown more in the last fifty years than over the previous five thousand years.

Several factors including an aging population, ever increasing health care costs, and consumer demand for healthier food have been significant driving forces in moving functional foods and nutriceuticals into the corporate mainstream. Interest in this area is growing extremely rapidly (Mazza, G. and Oomah, B.D., 2000). Consumers seek more goods not tied to simple survival.
Food in its traditional role will change from "survival and pleasure" to that of food as medicine. Antioxidants, such as carotenoids, vitamins E and C, flavonoids and glutathione, which are thought to play a role in the body's defence against cardio-vascular disease, cancer, arthritis and visual impairment, are a hot topic for the functional food industry in future. Food now has many different names: *"nutriceuticals, functional foods, dietary supplements, nutrional supplements, medical foods, fortified foods, foods for special dietary use, health foods, pharmafoods, cropceuticals, bioactive foods."*

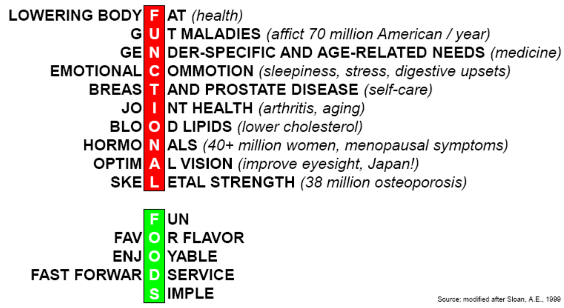
Transformation of the Eating-Culture



Source: Falk, P., 1994

The "graying" of the population has a variety of other consequences going beyond the limits of food requirements, food expectations, specific eating habits, food quality and, ultimately, primary food production and need not be considered here.

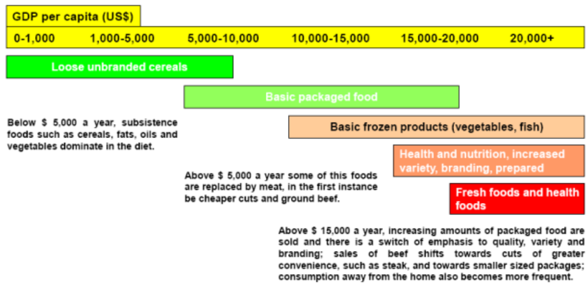
New Generation of Functional Food in the US, 1999



Source: modified after Sloan, A.E., 1999

As incomes rise for certain urban professional groups, people move up the food chain, i.e. consume more livestock products, the production of which either requires more grain or absorbs waste land.

Trigger Levels of GDP Per Capita for Different Types of Foods



Source: Steenkamp, 1997 in: The World Beef Industry, 1998

People living in urban areas, however depend on the market for nearly 90% of their food supply. So every time one person moves from a rural to an urban setting, the necessary market suppliers must increase by a factor of nearly 2 (McCalla, 2000).

Already today's 400 million or so subsistence farmers cannot feed the urban population of 1.5 billion; the 800 million subsistence farmers of the year 2025 will not possibly be able to feed 4 billion city dwellers.
This means that future food production will come from a dualistic agriculture. The subsistence sector will continue to support those living in the backward areas, while modern agriculture and intensified production will have to supply the urban dwellers.

Improving rural livelihoods will lead to reduce emigration and thereby ease the social and economic pressures on urban areas.

What are the future directions of agriculture?

Against the background of the developments described here in industrialized, newly in-

dustrialized, developing and least developed countries, together with the exponentially increasing need for food, the agriculture of the future will be increasingly multi-functional, heterogeneous, complex, multi-complex, knowledge-driven, technology-driven and adapted to available resources.
For this purpose, it will be important to encourage more fluid transitions between the various cultivation systems "rationalized agriculture", "value-added agriculture", "high output agriculture", "low external input farming", "precision farming", "prescription farming", "site-specific farming", "subsistence farming", "organic farming", "integrated farming", "progressive farming", "pioneering farming", "knowledge intensive agriculture"; synergies and symbioses will have to be studied, implemented and put into practice. More sophisticated technology will bring about a significant increase in the diversity of agricultural production systems.
The optimized and integrated use of all available technologies has to be implemented at farmer level. Extreme positions, such as organic farming focusing mainly on environment only and high cost intensive farming focusing on production, both have their niches, but cannot serve from a global point of view (Kern, M., 1998).

Quite apart from the high diversity of an agriculture adapted to available resources, it must always be remembered that resources such as soil, climate, water, technical know-how, knowledge, etc., are distributed unequally throughout the world, and that progress in agricultural technology will be implemented very rapidly in some regions, but hardly, if at all, in severely handicapped regions. Ultimately, there are two worlds when it comes to agricultural production: the haves and the have-nots.

"The haves"

The haves – North America, Europe, (Brazil, Argentina) and Australia – possess efficient cropland to meet most of their food needs and efficient agricultural production systems to allow sufficient food to be produced for export.
Agriculture functions well in preferred agricultural areas, with fertile soil, enough water and a generally favourable climate, and with farmers who are well educated, trained and informed, and have access to all agro technologies (inputs). They are going the way of research and knowledge-driven precision farming. Only less than 2 percent of the population are working in agriculture and the people living in these countries are paying less than 15 percent of their monthly income for their "vital" foods.
Out of a total of 1.9 million farmers in the US, less than 300,000 account for more than 80% of the out-put. The other 1.6 million produce less than 20% (McCalla, A., 2000).
In some modern industrial nations, agriculture has gone over from its traditional elementary function of food production to production of renewable raw materials, preservation of agricultural landscapes and nature conservancy, and ultimately has no other function than to stabilize the infrastructure of rural areas.

Technological changes are key drivers that shape agriculture. Logically they raise the following question:

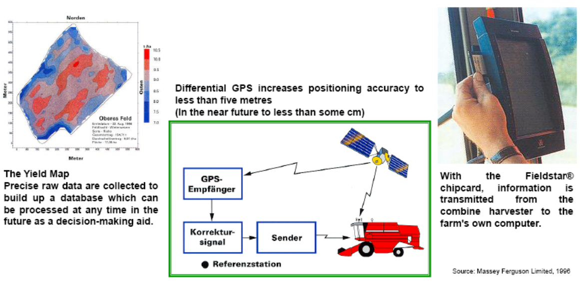
What are the key technological drivers which will push forward sustainable and essential high output agriculture?

One of the answers will be: Precision farming, biotechnology and genomics/functional agri-genomics.

Precision farming

Precision farming is a strategy that employs detailed and site specific information for managing production inputs. Precision farming will increase productivity by using fewer inputs, i.e., a more sustainable agriculture. This includes precise application of herbicides, fungicides, pesticides and fertilizer as well as finer adjustment of seeding rates.
Introduction of "precision farming" is a current buzz word in agricultural circles. The term "precision farming" means careful tailoring of soil and crop management to fit the different conditions found in each field. It has caused attention to be focused on the use of the Geographic Information System (GIS) and Global Positioning System (GPS) as well as the Near Infrared Vegetation Index (NVI) System. Some people incorrectly use the term "GPS" to imply precision farming only. We have literally taken "agriculture into the space age" (Johannsen, C.J., 1995). Farmers have access to services in which satellites collect data, transmit locational information, and provide data from a variety of sources. Farmers can analyze the satellite information or rely on companies to perform this service for them for a fee.

Differential GPS and Yield Mapping



The Yield Map
Precise raw data are collected to build up a database which can be processed at any time in the future as a decision-making aid.

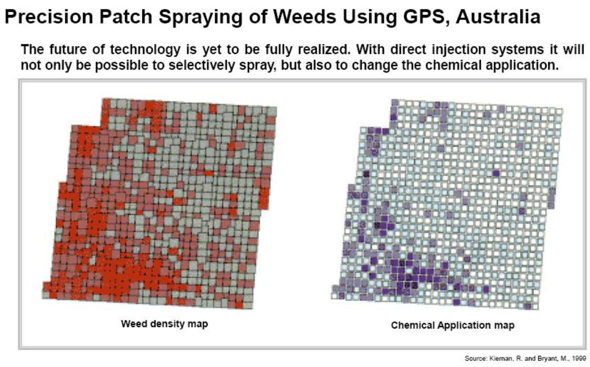
With the Fieldstar® chipcard, information is transmitted from the combine harvester to the farm's own computer.

Source: Massey Ferguson Limited, 1996

GPS makes use of satellites that identify the location of farm equipment within a few square centimeters of an actual site in the field in the near future. The value of knowing a precise location within inches is that:

1. locations of soil samples and the laboratory results can be compared to a soil map,
2. fertilizers and pesticides can be prescribed to fit soil properties (clay and organic matter content) and soil conditions (relief and drainage),
3. tillage adjustments can be made to allow for various conditions across the field, and
4. yield data can be monitored and recorded by simply moving across the field.

The application of chemicals and fertilizers in proper proportions are of environmental and economic concern to farmers. Using GPS together with a digital drainage map, the farmer can apply pesticides in a safer manner and in a more sustainable way.
Weed information may also be detected remotely from aerial photographs. The Near Infrared Vegetation Index (NVI) Spectrum allows weed infested areas to distinguished from stubble and subsequently mapped - selective sprays can be produced (Kiernan, R. and Bryant, M., 1999).



Seeding hybrid seeds perform best when spaced in such a way as to allow the plants to obtain benefits such as maximum sunlight and moisture. This is best accomplished by varying the seeding rate according to soil conditions such as texture, organic matter and available soil moisture. Since soils vary across an individual farm field, the ability to change seeding rates while moving across the field allows the farmer to maximize this seeding rate depending on the soil conditions. A computerized soil map of a specific field on a computer fitted on the tractor along with a GPS can tell farmers where they are in the field allowing the opportunity to adjust this seeding rate as they go across their fields.

Furthermore, the ability to vary the depth of tillage along with soil is very important to proper seedbed preparation, control of weeds and fuel consumption and therefore cost to the farmer.

The real value for the farmer is that he can adjust seeding rates, plan more accurate crop protection programs, perform more timely tillage and know the yield variation within a field. These benefits will enhance the overall cost effectiveness of his crop production.
Wide use of satellite-controlled sowing, fertilization and harvesting (2010) as well as of robots for cultivation, harvesting, sorting and post-harvest processing (2014-2018) is forecasted by Frauenhofer-Institute (Delphi '98, 1998). Digital technology clearly will open up bold new economic vistas in rural places.

Biotechnology

In 1999 world-wide more than 70 transgenic plants were registered (cotton, chicory, potato, pumpkin, corn, soybean, oilseed rape, papaya, tobacco, tomato, clove). Up to now more than 25,000 field trials have been carried out world-wide. Today genetic modifications of more than 100 plant species are growing in laboratories, greenhouses or in the field throughout the world.

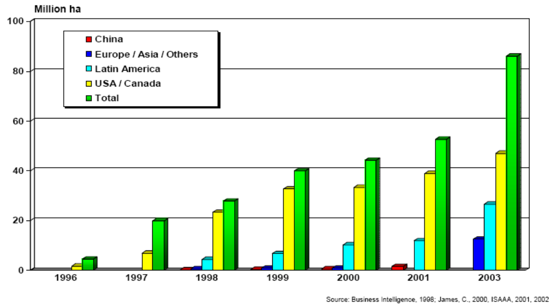
The first wave of biotechnology crops is already in the field. It provides farmers with agronomic traits that simply make it easier for farmers to grow their crops more easily and profitably. In addition, the biotechnology crops contribute to more sustainable agriculture as farmers use fewer agricultural chemicals, conserve topsoil and water, and reduce fuel use.
Furthermore, agro-biotechnology makes an important contribution to integrated crop production (ICM) and leads to a further dematerialization of agriculture, precision farming and last but not least to sustainable agriculture. Dematerialization stems from a better understanding of agricultural systems, which leads to optimal use of scarce and expensive inputs, greater efficiency and less waste (Kern, M., 1999).
Clearly, farmers and industry experts around the globe are convinced that transgenic crops offer a significant improvement, otherwise the adoption rate would be much lower.

Genetically optimized crops in North America (1996-2003) will be grown on more than 60% of the total crop area. It is forecast that in the year 2003, around 60% of the crop area will be genetically modified (GM) corn, soybean and cotton, 20% GM potato, 30% GM tomato, 40% GM sugar beet, and nearly 75% GM oilseed rape.

In 1999 the global area under genetically optimized crops was 40 million hectares and will reach 85 million hectares (15 million hectares in Europe/Asia/Others, 25 million hectares in Latin

America and 45 million hectares in the USA/Canada) in the year 2003 (6% of the total global arable land).
In North America, South America, Australia, India, and China commercial realization of biotechnology crops is under way.
In Europe, the whole issue is hampered by unresolved political deliberations.

Genetically Engineered Crops Grown Worldwide, 1996 - 2003

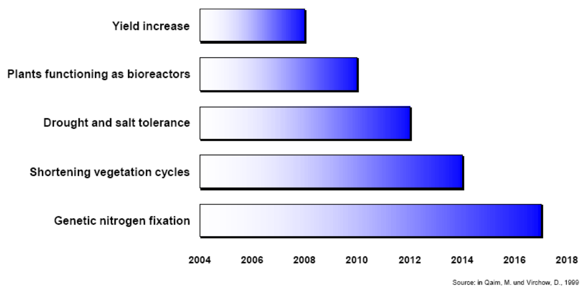


The second wave of agro-biotechnology will reach the fields in 2002-2005; the qualitative (output) traits will be modified. These traits will change the nature of the crop itself. "Commodity crops" (wheat, corn, canola, soybean, rice) will have a higher quality as well as a higher market value. It is only a matter of time before new crop biotech-nology products come on to the market.

The third wave, i.e. the production of genetically optimized plants, nutriceuticals, probiotics or, ultimately, even medicaments can be expected after 2005.

Around 2010 there will be genetically modified plants which produce special chemicals, for example potatoes which will be used for the production of paper, biological adhesives or detergents.

When Will Genetic Methods Be Sophisticated?



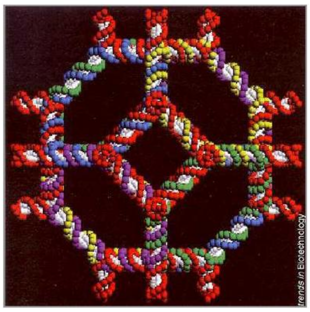
Genomics/functional agri-genomics

Genomics is concerned with the mapping and sequencing of genes (structural genomics) and to the assessment of gene function on the basis of the information thus obtained (functional agri-genomics).

The importance of agri-genomics to the future of crop production is well described by McLaren, from Inverizon International Inc., USA (McLaren, J.S., 2000).
Genomics, and especially functional agri-genomics, will prove to be one of the major keys in capturing the promising benefits of crop biotechnology. The use of new tools in crop breeding will allow more precise, more easily measurable and more beneficial traits to be added to crops around the world and enhance the quality of life for billions of people.
The scope of possibility is highly impressive: one thousand grams of DNA (dissolved in one cubic meter) would have a larger storage capacity than all computers which have ever been built, or about 100 billion times the storage capacity of our brain. Thirty grams of DNA work one hundred times faster than the fastest computers we know today (Kaku, M., 1998).

The genetic code of life is a gigantic biological manuscript that we have scarcely yet begun to examine or decode. An important goal will be to determine the function of a gene, in silico, in vitro and in vivo.

Biotechnology as a Route to Nanotechnology



A computer-generated image of a truncated octahedron that was synthesized from DNA by N. Seeman.

Source: Merkle, R.C. in TIBTECH, 7/1999

What will be established within the next couple of years?

1. Genetic maps, for identifying and localizing traits on the chromosomes.
2. Cytological maps, for visualizing chromosomes and bands corresponding to traits and for localizing genes on the DNA.
3. Physical maps, describing the complete nucleotide sequences.

Genomic research will enable us to identify and validate new targets for insecticides, herbicides and fungicides, nematicides, and to determine the mode of action of active ingredients.
Crop protection products will be essential to maintain the levels of production and security of food supply in the coming century (Yudelman, M. et al., 1998; Brooks, G. and Roberts, T., 1999).
In future, sustainable pest control will depend very greatly on developing new strategies and tactics,

and functional genomics will offer an effective tool box in a continuing game.
It will also place us in a position to identify new genes and gene functions to enable us to discover and validate new traits for seed improvements (Kern, M., 2000).
Over 15 organisms have been fully sequenced, the genome of more or less all relevant plants will be analyzed within the next 5 to 10 years.
Functional genomics will enable us to understand how the genome relates to the phenotype. Marker-assisted breeding will be an essential instrument for future seed improvements. It will shorten the breeding program from 10-12 years to only 2-4 years. The ability to introduce enhanced traits more rapidly to elite germplasm will be a key for future crop improvement (McLaren, J.S., 2000).

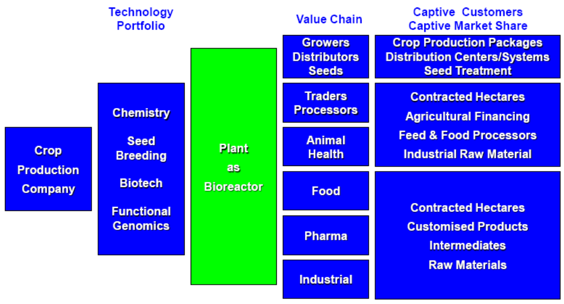
How can we improve the value creation chain in plant production?

New plant breeding technologies will make it possible in about 10 to 20 years to use gene switches to initiate production of special substances, e.g. pharmaceutical active ingredients, in the field, and improved resistance management, and also to eliminate or control pests with crop plants possessing inbuilt control mechanisms which can simply switch certain genes on or off as soon as a particular pest appears. If this new "gene switch and chemical switch" technology is properly developed, it will doubtless become the key to a major value creation for chemistry in agriculture.

The sweeping changes in the market make it necessary to offer new preparations in the form of plant protection solution packages. Companies in future will form scientific platforms which they share with their customers. The changes in distribution structures resulting from e-business will reinforce customer binding. New products will become innovations if they are able to perform within the framework of an overall value creation chain (Stübler, H., 2000). On the other hand, the agribusiness consumer will raise much more specific demands on the quality and identity of products, e.g. food. He will want to know how they have been produced. The companies producing agrochemicals and plants will take the demands of the processing industry and the consumers into account by means of intensive relationship management with their new products.
The integration of seed business into the modern plant production and agribusiness industry, and also the drastic changes brought about by e-commerce or e-business, will lead to marked changes in value creation in the agricultural business processes. It will no longer be new products alone which create value, but overall package solutions.

Specialized supply chains will spring up. Rural communities that hitch themselves to the new agriculture will benefit from the jobs that processing activity will bring, as well as the prospect of higher incomes for large local producers (Drabenstott, M., 1999).

Agriculture 2025: Consequences for Future Players



"The poor have-nots"

The poor have-nots make up the bulk of the developing world. These countries contain over three billion people, and for many reasons they cannot produce or import enough food for their populations. In many cases their food production capacity is deteriorating in the face of rapid population growth, misdirected agricultural policies, wars and widespread land degradation.

These countries or areas are poor in resources, highly heterogeneous and risk-prone. In humid or sub-humid areas and in the semi-arid tropics and subtropics, the farming systems are complex, the soil fragile and the weather highly variable. These are also the regions most likely to be negatively impacted by global warming. The most poverty is actually in arid or semi-arid zones and in steep hill-slope areas that are ecologically unstable. Agriculture in these areas is limited by low rainfall and limited potential for irrigation.

Sub-Saharan Africa's Food Insecurity

- poor marketing and processing systems
- outdated production techniques
- insufficient investment in farming
- low investment capacity
- ineffective agricultural services
- soil fertility problems
- unpredictable climatic conditions
- poor administration and funding of research
- poor management of natural resources
- low competitiveness of African farm products
- lack of interest among young people (see India, China)

Source: Ugwuanyi, J.U. and Obinne, Ch., 1998

Agricultural productivity there is very low, the arable land is of low fertility, and production is mostly for own consumption. Most of these regions have high deficits in basic needs, such as nutrition,

education, health and water, and they have no or only partial access to agro technologies (inputs).
In such a type of subsistence farming more than 80 percent of the people are engaged in agriculture, most of them women and children. Nearly 90-100 percent of their "monthly income" has to be spent for food only.
In most developing and least developed countries the size of small family farms has been halved over the past four decades, as plots are divided into smaller and smaller pieces for each new generation of male heirs. In 57 developing countries surveyed by the FAO in the early 1990's, over half of all farms were found to be less one hectare in size, not enough to feed a family with four to six children (Hinrichsen, 2000).
To make matters yet worse, erosion and desertification now threaten 40 percent of Africa's non-desert land and 30 percent of Asia's production area.

Sub-Saharan Africa's Food Insecurity

Adedeji (1993) identified limited use of new technologies as a primary cause of low agricultural productivity in Africa.

Many analysts agree that the alleviation of poverty and hunger will not follow from the market reforms of the World Bank/IMF SAP (Structural Adjustment Programme) unless it is backed up by increased investment in terms of improved seeds, new breeds, and increased use of agrochemicals and farm machines.

On the failure of SAP, Olusegun Obasanjo observed that Africans must determine their agenda, which must be consistent, stable and based on their needs and outlook, and must not reflect the desires and wishes of donors.

Source: Ugwuanyi, J.U. and Obinne, Ch., 1998

What are the key drivers which will push forward a more sustainable "low external input" agriculture?

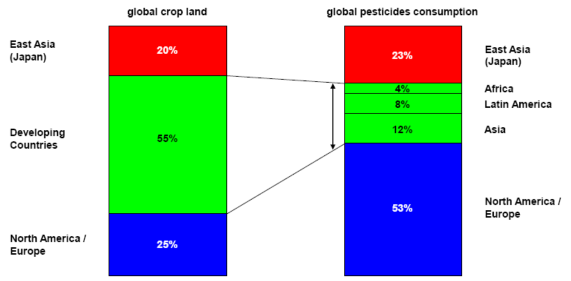
Technological changes are key drivers that shape agriculture.

Agro-inputs are: organic and chemical fertilizers, herbicides, pesticides; seeds/biotechnology; technology transfer; knowledge/information/education.

Agro-Inputs

Short- and midterm, the most effective technology will be a combination of locally available inputs with selectively applied external inputs. Beside green manure, dung and compost, chemical fertilizers will be intensively used to increase crop production. Farmers who use the right amounts and type of chemical fertilizers suffer far less crop loss from competition for light and nutrients, or from infestation. When no fertilizers are applied, diseases easily penetrate into the fields.
The balanced use of organic and chemical fertilizers, herbicides and pesticides described by Ruben and Lee (2000) will help farmers consistently to raise land and labor productivity and maintain sustainable resource management practices (Yudelman, M. et al., 1998).
Nevertheless, the high labor requirements of subsistence or low external input agriculture may reduce returns to labor, and family labor constraints may hinder adoption. Combining internal and external inputs will be essential for a sustainable intensification of food production.

Annual Pesticide Consumption in Various Regions



Pesticides are used only in about one-third of the total cropped area in the world *(Oerke et al., 1995)*

Source: Schaeffers, 1992 in: Yudelman, M. et al., 1998

Seeds / Biotechnology

Seed is the basic agricultural input for and required for a sustainable agriculture.
"Seed is in fact the hub around which all other strategies to improve productivity resolve" was said by Sehgal (1999). More than 50 percent of the rate of yield increase is due to genetic improvement. Improved farming techniques, agro chemicals and machinery are only as effective as the germplasm they support. This means that farmers everywhere require a secure source of good quality seed for good harvests. Access to improved seeds adapted to local demands will be a key for sustainable intensification. Significant contributions will be made by the public and private sectors.
Let me refer to Suri Sehgal again. The seeds that farmers require must be bred for the areas in which it is to be grown and extensively evaluated there before it is released on a large scale. Further, an improved hybrid or variety is useless unless its seed reaches the farmers in sufficient quantity, and has high quality and good purity. Farmers in the developing world have to and will establish a local industry involved in the breeding, production and distribution of seeds in order to meet their particular needs.
Many crops of importance in the developing world are today not in the focus of interest to multinational seed companies, even to those operating in developing countries. For this reason it will be important to support the development of an indigenous public and private sector seed industry. Smallholder agriculture will benefit significantly from such seed improvements. For example hybrid rice (average yield of 6.8 tons per hectare) which have revolutionized rice production in China will be available in more or less all Asian countries. Seeds tolerant to abiotic stress will be

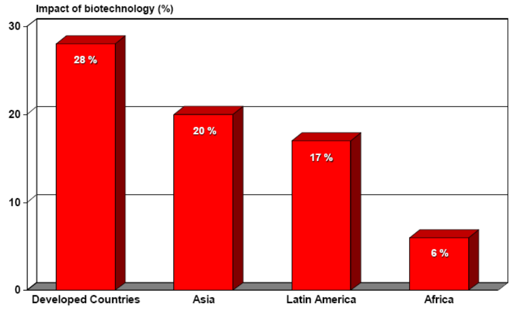
developed and sold or distributed to farmers living in low potential areas – a significant contribution to sustainable agriculture and livelihood.

Unfortunately the speed of development, implementation and utilization of genetically modified crops in the developing world is unsatisfactory, although the enormous potential of biotechnology is well known. For example, FAO (1997): *"Biotechnology, particularly the genetic engineering of plants or animals to meet specific needs, holds much potential for meeting the challenge of increasing productivity and conserving natural resourses".* AGENDA 21 (1992), Chapter 16: Biotechnology, expressly propagates gene technology:
"Biotechnology, an emerging knowledge-intensive field, is a set of enabling techniques for bringing about specific man-made changes in deoxy-ribonucleic acid (DNA), or genetic material in plants, animals and microbial systems, leading to useful products and technologies. By itself, biotechnology cannot resolve all the fundamental problems of environment and development, so expectations need to be tempered by realism. Nevertheless, it promises to make a significant contribution in enabling the development of, for example, better health care, enhanced food security through sustainable agricultural practices, improved supplies of portable potable water, more efficient industrial development processes for transforming raw materials, support for sustainable methods of afforestation and reforestation, and detoxification of hazardous waste".

"Biotechnologies in developing countries: present and future Vol 1: Regional and national survey" (Sasson, A., 1993) presents an important overview of the status of biotechnology research and development in the developing world, through a regional and national survey (1.670 pages). While describing the situation in the early 1990s, it also includes forecasts for the end of the decade, and contributes in this way to the understanding of the economic and sociocultural implications of biotechnologies. A further overview is given by de Kathen (1999).

The quantitative contribution of biotechnology to securing global food supplies in the various regions of the world - which is not the same thing as eliminating hunger in the world - will be on the following lines. In 2025, 28 percent of the food production in the developed world (USA, Europe, Australia, Canada, CIS) will be accounted for by genetically modified materials. Asia will achieve 20 percent of its food production with GMO food, Latin America 17 percent, and Africa only 6 percent.

The Quantitative Impact of Biotechnology on Food Production, 2025



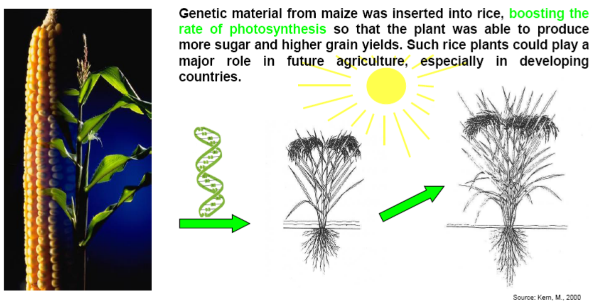
There are two reasons for this very low share in Africa. The first is that there are scarcely any lucrative segments for biotechnology in Africa. Especially while this technology is still at the introductory stage, private companies will tend to concentrate on profitable markets, mostly in the industrial nations. The second reason is that, in the western world, the risks of GMOs are the subject of a very heated and often contradictionary public discussion, or are condemned entirely. The conclusions drawn from this can be described very briefly as follows: as long the risks have not been one hundred present clarified, there will be no transfer of this technology to the third world. As I see it, this will be yet another example of the way we so often make use of new technologies and leave the third world behind technologically by another 20 to 30 years. Many years experience in scientific research have shown me that, if I start gene technology research now to help solve a typical African problem, it will be at least 10 to 15 years before I come on the market with a solution. A noticeable delay in introducing biotechnology will have the effect of keeping the contribution of biotechnology in Africa down to only about 6 percent.

However, studies in Kenya and other African countries (Wambugu, 1999; Qaim, 1999) have shown that the technology and products were easily adopted by farmers. The "quality/technology is in the seed" and farmers do not need to alter their traditional farming practices to obtain tremendous benefits.
Insect-resistant cabbage, for example, is not cultivated in any other way than non-insect-resistant cabbage. Insect-resistant cabbage is not devoured by cabbage moths and thus safeguards the harvest. Here, then, is a possible way to increase and safeguard yields.
But the real questions are: What are we going to do about it? How is this key technology to be put into the hands of small farmers in, for example, the Himalayas? What value enhancements in plants are necessary, and beneficial in the long term?

Potential benefits of genetically modified rice was announced in January 2000, called "golden rice", because of the color caused by the modification. This adds vitamin A to the grain - which could cure the vitamin A deficiency of 124 million children worldwide. The deficiency causes blindness. "Golden rice" was developed by the Swiss Federal Institute of Technology, by inserting three genes into the rice; these make the plant produce beta carotene or provitamin A. It will be made freely available to farmers in developing countries.

New scientific breakthroughs were published recently. Genetically modified rice which could boost yields by up to 35 percent was developed jointly by Washington State University and agricultural researchers in Japan (Brown, 2000). Genetic material from maize was inserted into the rice, boosting the rate of photosynthesis so that the plant was able to produce more sugar and higher grain yields. Such rice plants could play a major role in future agriculture, especially in developing countries.

Genetic Modified Rice Which Could Boost Yields by up to 35%
(Brown, 2000)

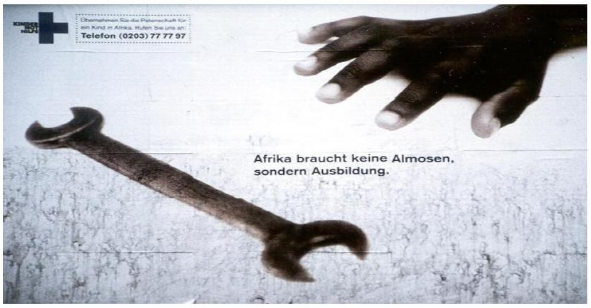


Joint research by Bayer CropScience and the Biotechnology Institute of the University of Cambridge in England recently achieved more rapid growth by an increase in the rate of cell division. After an Arabidopsis gene responsible for cell division had been integrated into a tobacco plant, it became possible to obtain a doubling of the growth rates. This achievement opens up the possibility in future to speed up vegetation periods and secure several harvests per year, thus at the same time bringing about an overall increase in productivity. This result would also make a simplified and more cost-effective contribution for active ingredient production in plants.
An intensive implementation of biotechnology in developing countries will be an important contribution for safeguarding world food security and feeding mankind.

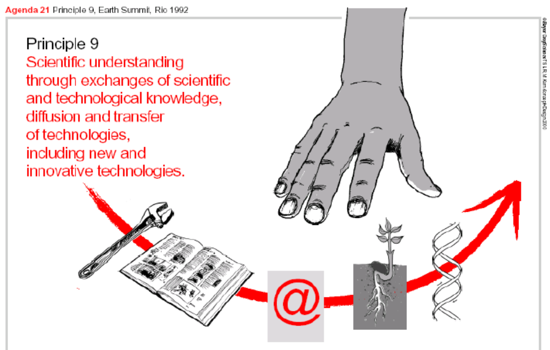
Technology transfer

In all probability we could make food available throughout the world with the agricultural technology already at our disposal. But it is the political parameters which loom large against the background of multitudes of poorly nourished people. Charitable contributions alone will not solve the problem. – Please understand this rightly. A one-minute item on "hungering humanity" in the evening TV news, together with an inserted bank account number, is worth a million marks in donations. But this cannot be the basis for planning long-term projects which open up prospects for the future. Money donations do not usually solve the hunger problem – at best they can alleviate it. Once the cameras have been packed away, the donors will have forgotten the matter. An awareness of existential problems in the developing countries cannot be aroused so very easily among the population as a whole. Many Germans, for example, can no longer be shocked by pictures of famine and hungering refugees.
An advertising placard before Christmas 1998 rightly called for education rather than for alms-giving. Africa or developing countries do not need alms, they need education. This must be very strongly emphasized, and even extended: "Not only education but access to available agricultural technologies and more especially, to modern key technologies".
The only thing wrong with this advertisement was the technical level. The technical level is no longer the screwdriver displayed on the placard, but the key technologies used in the advanced countries, or being developed there at the moment. The developing and least developing countries must catch up on the new technologies, and the sooner the better.

Africa Needs No Alms, But Education



Agenda 21 Principle 9, Earth Summit, Rio 1992



Knowledge/Information/Education

A global vision for agricultural research for development documented as the *"Dresden declaration: Towards a global system for agricultural research for development"* at the end of the Global Forum on Agricultural Research (GFAR) from 25th May, 2000 in Dresden, Germany, required sustainable research partnerships between the public and the private sectors as well as strong support by policy and decision makers. The GFAR stakeholders committed themselves to establish a Global System for Agricultural Research for Development as follows:

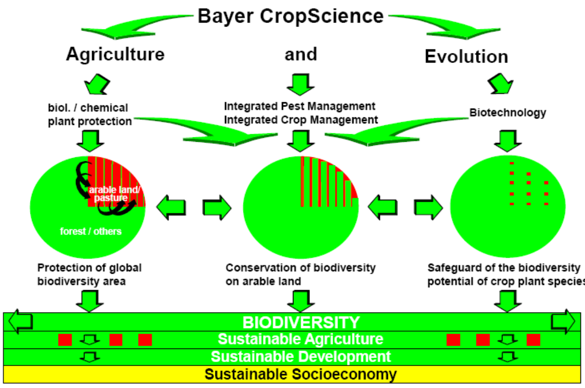
1. the formulation of a global strategic research agenda which capitalizes on the comparative advantages and the strengths of the different GFAR stakeholders;
2. the promotion of innovative, participatory, cost-effective and sustainable research partnerships and strategic alliances;
3. the information and communication technologies (ICT) networking among stakeholders and the establishment of specialized agricultural knowledge and information systems.

The realization of this vision will significantly improve sustainable agricultural production systems especially in developing countries. Within this context, it will be essential to bring the messages across - to rural as well as urban people all over the world.

Which strategy we will use in future for sustainable crop production?

Everywhere in the world the overall key element of future agriculture will be the concept and the realization of Integrated Crop Management (ICM) to meet the requirements of sustainable development and sustainable agriculture by managing crops profitably without damaging the environment or depleting natural resources for future generations. It is a dynamic system which uses the latest research, technology and experience in ways that suit local conditions in order to optimize food production, enhance energy conservation and minimize pollution worldwide. A broad spectrum of the successful ICM-programs already realized is documented by Bayer CropScience 2000.

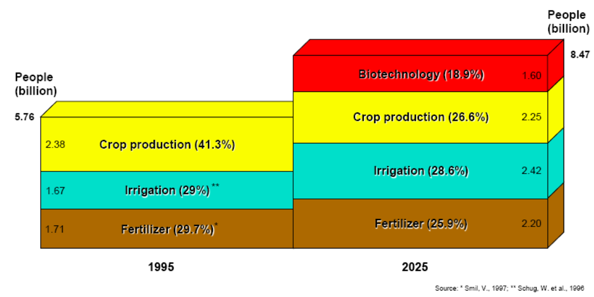
ICM will enable an Integrated Resource Management (IRM) as well as Integrated Plant Nutrition Systems (IPNS) which integrate all controllable agricultural production practices to provide long-term sustained productivity of safe and wholesome food in an environmentally sound manner.



What can we expect from agrotechnologies in the future?

Nowadays it is generally reckoned that 1.7 billion "owe" their food to fertilizer inputs, another 1.7 billion to intensive irrigation, and 2.4 billion to plant protection and plant production together with the specialized knowledge and expertise of farmers throughout the world. This picture will change. The use of fertilizers will, on the whole, increase dramatically, especially in developing countries, but not in Western Europe. The level here is about 100 kg per hectare, which is already at the optimum limit. Irrigation systems will be extended - you will already be familiar with all the major reservoir projects around the globe. The share of plant protection will be less than it is at present. It is assumed that 1.6 billion people (18-20 percent) in 2025 will owe their food to the use of genetically modified organisms. Insect resistance, modified fatty acid spectra in plants, tolerance to biotic and non-biotic factors, and renewable raw materials in the form of starch modifications or bio-plastics and bio-detergents are just some of the steps along this road.

World Population and Agricultural Technologies



Why do we need co-operations?

There is no sense in considering technological components in isolation from ecologic, economic, political, social, ethical and demographic factors.
By means of an intelligent integration of all agrotechnologies and of suitable social and political conditions, it will be technically possible to make sufficient food available and reduce hunger

significantly at regional level. To do this, as Qaim and Virchow (1999) rightly insist, it will be necessary to have a constructive dialogue or cooperation between farmers, scientists, the economy, NGOs, politicians and consumers - with all sides being prepared to make concessions.
Poverty and hunger must be fought on many fronts. New jobs in the countryside are just as important as efficient family planning.

The private sector will have to develop or present new solutions to problems in markets where short- or medium-term profits must be made. For this purpose market structures must already exist or must be easy to establish, and care must be taken to ensure that investments enjoy sufficient protection. Private research, especially from the industrial countries, will find itself increasingly under an obligation to develop new technologies and help adapt these to local conditions in the developing countries.

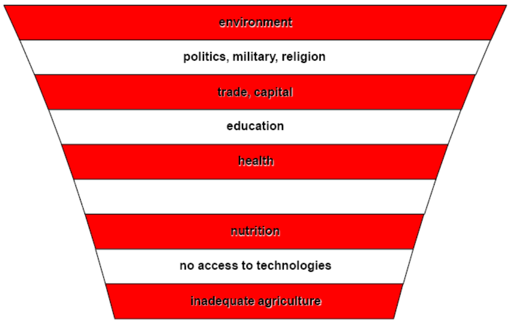
Adaptation of the private sector's technology to the developing countries requires in all cases:

1. proper regulatory environment to secure global deregulation standards,
2. enforceable intellectual property protection,
3. national/international technology transfer infrastructures incl. analytical capabilities to monitor GMOs,
4. development investments, and
5. a local seed industry.

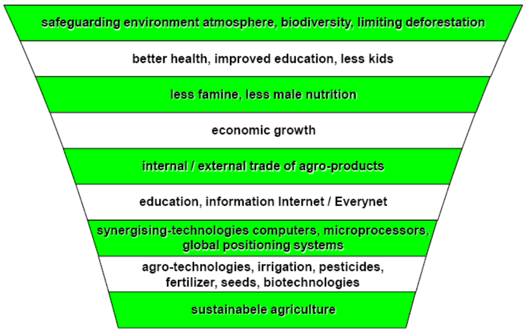
Governments will have to support public research facilities but at the same time encourage the private sector, i.e. industry. Seed breeders, biotechnology companies and many other companies associated with agriculture are becoming partners. Only if we all work together we will be able to find solutions that will enable sufficient food to be produced in a sustainable way. A valuable and informative UNESCO-documentation of international co-operations under the title *"Biotechnologies in developing countries: present and future Vol 2: International co operation"* has been provided by Sasson (1998).

The vicious levels of poverty as well as of global food security is shown in the next figures.

Vicious Level of Poverty: Africa



Vicious Level of Global Food Security



The integration of all technologies, including biotechnology/genetic engineering, will make it possible to meet the increased needs for food without extending agriculture into areas of high biodiversity and also to develop agricultural systems which conserve diversity within the system itself.
In future we can expect a more sustainable agriculture, which will be the foundation of better crops, better nutrition, advanced jobs, and better livelihood in an intact environment.

What do people and farmers need?

The answers given by Simon Maxwell (1996, 1998) in the Charter for Food Security point out the direction to be taken:

The world needs to produce more food, to feed a growing population...

1. Farmers need fair prices. All farmers are guaranteed at least 80 per cent of the international price for the products they sell, adjusted for transport and processing costs. If the private sector cannot do this, the state will intervene.
2. Farmers need inputs. All farmers are guaranteed access to agricultural inputs, on time, at competitive prices. Again, if the private sector cannot cope, the state will act.
3. Farmers need to be able to market their produce. The state will ensure that 80 per cent of farmers are less than five miles from a publicly maintained all-weather road, wherever it is economically and socially desirable to do so.

4. Farmers need new and environmentally sustainable technology. All farmers will be supplied with information about new technologies that will increase income in a profitable and sustainable manner by at least 5 per cent.

But in addition, poor people must be able to obtain food...

5. Poor people need a livelihood. Every adult is guaranteed a minimum income, in cash or kind, sufficient to guarantee subsistence, in good years and bad. Where self-provisioning and the market fail, the state will set up employment schemes or otherwise provide income transfer.
6. People need access to shops. Every food consumer will have access to shops selling safe food at competitive prices, in all seasons and all years. If necessary, the state will stock these shops.
7. Refugees and the victims of war need special measures. Every refugee is guaranteed a minimum diet adequate in quantity and quality.

Mothers and children must be protected,

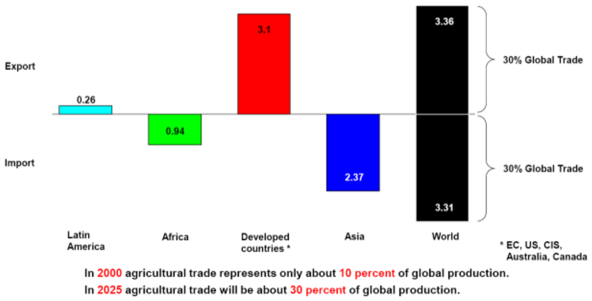
8. Mothers and children must be protected against malnutrition. Every woman of child-bearing age and every child is guaranteed a yearly health and nutrition check by a qualified health worker.
9. Every pregnant woman showing nutritional deficiency and every child exhibiting growth faltering, is guaranteed participation in a health and nutrition programme.

And democratic rights must be safe-guarded.

10. Achieving food security is a political and not just a technical matter. People have the right to be consulted in a democratic process about matters which affect their right to food.

We will double the size of the world economy in just 12 years, doubling it twice in just 25 years. By the year 2025 more than 30 percent of all foodstuffs worldwide will be exported or imported. While the new agrotechnologies increase in importance or even assume top priority, trade will also come to assume a key position in making food accessible and available to people in sufficient quantities and optimum quality. WTO negotiations, GATT agreements and intellectual property rights will have a decisive influence on crops, jobs and livelihood.

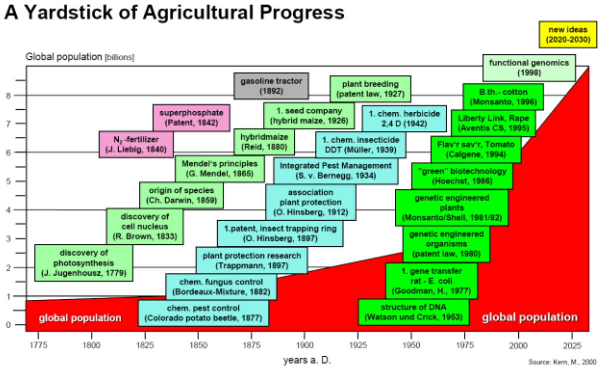
Global and Regional Agricultural Export / Import: 2025
Trillion Kilocalories per Year



What was the yardstick of agricultural progress and what do we need to have a sustainable agriculture in the next millennium?

Let us finally have a look at the yardstick of agricultural progress. In recent history, let us begin with the discovery of photosynthesis by Jungenholz in 1779. From then until the invention of the first photosynthetically active herbicide, atrazine, in 1957, 178 years passed. Between the first discovery of the cell nucleus by Brown in 1833 and the establishment of the first seed company in 1926, 93 years passed. The innovation in fertilizers introduced by Liebig in 1840 was intensively used after World War II. Between the first report on chemical control of the Colorado potato beetle in 1877 and the synthesis of the first insecticide in 1939 by Müller, there was a period of 62 years. The time span between the analysis of the structure of DNA by Watson and Crick in 1953 and the first patented genetically engineered organism in 1980 and the first commercial introduction of a genetically modified plant, the insect resistant, B.t.-cotton, was a mere 46 years. The next break through related to functional agri-genomics will be implemented within 10 to 20 years.

A Yardstick of Agricultural Progress



These simple examples suggest that changes are not progressing in a linear way, but with a positive, non-linear acceleration. Fortunately, the increasing speed of at which agro-technologies are being implemented is in line with the exponential growth of world food demand and safeguards world food security, today and in future.

Within this context we have an optimistic vision of what the future can be (Kern, M., 1999).

Positive thinking people with long-sightedness have recognized that agro-technologies have a promising long-term potential and will ultimately make an indispensable contribution towards safeguarding world food supplies, alleviate poverty, avoid migrations and protect natural recourses. Socioeconomically, biotechnology and functional genomics are considered to be of strategic importance.
The future must bring markedly more efficient use of land, energy and material – in a short, a superior "industrial ecology". Within this context, our future task is not to do everything which is technically possible, but to do everything which is genuinely necessary.
In all discussions about research, development and commercial applications of biotechnology in crop agriculture it should kept in mind Indira Ghandi:
"How can we urge the preservation of animals, how can we speak to those who live in villages and in slums about keeping the oceans and rivers and the air clean, when their own lives are contaminated at the source? The environment cannot be improved in conditions of poverty, nor can poverty be eradicated without the use of science and technology."

Over the last few decades, progress has been made at a previously unimaginable rate in the most varied branches of scientific research - agriculture included. At the present time, in the year 2000, we can draw on a potential of over six billion people - as compared with only one billion in 1850 - for the knowledge we will need tomorrow. It must be remembered that development in agriculture are properly understood in hindsight, but we will need foresight to build up knowledge and technologies and put them into use at the right moment. We should not make the mistake, as almost all generations do, of underestimating our own potential for innovation, i.e. for new ideas and discoveries. It is already time to tackle the question: **"What will be equivalent in the twenty-first century of the discovery of the electron and of DNA?"**

References:

Bailey, R., (ed.) Earth Report 2000, Revisiting the True State of the Planet, Competitive Enterprise Institute, McGraw-Hill, New York, 2000.
Brooks, G.T. and Roberts, T.R., (eds.) Pesticides, Chemistry and Bioscience - The Food - Environment Challenge, The Royal Society of Chemistry, Cambridge, 1999.
Brown, P., Unveiled: the GM rice that could feed world, http://www.mg.co.za/mg/news/2000mar2/31mar-genetic.html, 2000.
Conway, G., The Doubly Green Revolution, Food for All in the 21st Century, Comstock Publishing Associates, Cornell University Press, Ithaca, New York, 1997.
De Kathen, A., Transgenic Crops in Developing Countries **-** A report on field releases, biosafety regulations and environmental impact assessments, Umweltbundesamt Texte 58, Berlin, 1999.
Drabenstott, M., Meeting a New Century of Challenges in Rural America, http://minneapolisfed.org/pubs/region/99-12/rural.html, 1999.
Frauenhofer-Institut für Systemtechnik und Innovationsforschung, Delphi'98, Studie zur globalen Entwicklung von Wissenschaft und Technik, 1998.
Ghandi, I., in: Falvey, L., Agricultural education in natural resource management, The Crawford Fund of International Agricultural Research and Institute for International Development Limited, Melbourne, Australia, 1996.
Greiling, W., Wie werden wir leben? Ein Buch von den Aufgaben unserer Zeit, Econ Verlag, Düsseldorf, 1954.
Groombridge, B. and Jenkins, M.D., Global Biodiversity - Earth's living resources in the 21st century, World Conservation Monitoring Centre, World Conservation Press, Cambridge, 2000.
Heaton, G, Repetto, R. and Sobin, R., Transforming Technology: Sustainable Growth in the 21st Century, World Resource Institute, 1991.
Hinrichsen, D., Feeding a future world, http://www.oneworld.org/patp/pap_7_1/hinrichsen.html, 2000.
Johannsen, C.J., An Overview on Precision Farming, http://www.giannottitech.com/prefarmoverview.htm, 1995.
Kaku, M., Zukunftsvisionen, München, 1998.
Kern, M., Sustaining High Output Agriculture, The World Bank, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Sustainability in Agriculture Systems in Transition, October 20-22, 1998, Baltimore, Maryland, USA, 1998.
Kern, M., Technological opportunities **-** biotechnology, Harvard Seminar on Health and Agricultural Research in Africa: Technological Opportunities and Institutional Challenges, Centre for

International Development at Harvard University, May 1999, Cambridge, MA, USA, 1999.

Kern, M., An die Grenzen des Notwendigen - Biotechnologie als integraler Bestandteil nachhaltiger Landwirtschaft im 21. Jahrhundert, Haushalt & Bildung Heft 4, 14-18, 1999.

Kern, M., Welternährungssicherung - eine Herausforderung für Forschung und Wissenschaft, Deutsche Gesellschaft für Agrar- und Umweltpolitik e.V. (DGAU), Meinungen zur Agrar- und Umweltpolitik Heft 35, 49-118, Bonn, Germany, 1999.

Kern, M., Highlightening the Agenda 21 - "Visualized Agenda 21", EXPO 2000, The Global Dialogue: The Role of the Village in the 21st Century: Crops, Jobs and Livelihood, August 15th-17th, 2000, Hanover, Germany, 2000.

Kern, M., Entomology for the Third Millennium - Scientific and Technological Challenges, Closing plenary lecture: XXI International Congress of Entomology, August 20th to 26th, 2000, Foz do Iguassu, Brazil, 2000 (in press).

Kiernan, R. and Bryant, M., Precision Patch Spraying of Weeds, http://www.rinex.com.au/news.phtml, 1999.

Maxwell, S., A charter for food security, Food Policy 22/6, 469-473, 1997.

Mazza, G. and Oomah, B.D., Functional Food Products from Selected Canadian Crops, 2000. http://www.ift.org/international/vol_1/focus1-1.shtml

McCalla, A., Agriculture in the 21st Century, CIMMYT Economics Program, Fourth Distinguished Economist Lecture, Mexico, D.F., CIMMYT, 2000.

McLaren, J.S., The importance of genomics to the future crop production, Pest Management Science, 56, 573-579, 2000.

Merkle, R.C., Biotechnology as a route to nanotechnology, TIBTECH, 17/7, 271-274, 1999.

Ruben, R. and Lee, D.R., Combining internal and external inputs for sustainable intensification, IFPRI, 2020 Brief 65, 2000.

Saint-Exupery, A., The wisdom of the sands, 1948.

Sasson, A., Biotechnologies in developing countries: present and future (Vol. 1/2), UNESCO Publishing, United Nations, Imprimerie des PUF, Vendome, France, 1993/1998.

Schartz, P. and Leyden, P., The Long Boom: A History of the Future, 1980-2020, 1998. http://www.wired.com/wired/5.07/longboom.html

Sehgal, S., Agricultural Biotechnology and Seed Industry: Some Implications for Food Production and Security, in: Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor, Qaim, M., Krattinger, A. and von Braun, J. (eds.), Kiuwer Academic Publishers, 2000.

Sloan, A.E., One Big Fat Market, FoodTechnology 52/4, 28-38, 1998.

Stübler, H., Forschung und Entwicklung - Neuorientierung und Aufbruch am Beispiel einer Life Science Industrie, Vortrag anläßlich der Handelsblatt-Jahrestagung, 4. 5. 2000, Frankfurt, 2000.

Spedding, C.R.W., Agriculture and the Citizen, Chapman & Hall, London, 1996.

Qaim, M., The Economic Effects of Genetically Modified Orphan Commodities: Projections for Sweetpotato in Kenya, ISAAA Briefs 13, published in collaboration with Center for Development Research (ZEF), Bonn, 1999.

Qaim, M. und Virchow, D., Macht Grüne Gentechnik die Welt satt? Herausforderungen für Forschung, Politik und Gesellschaft, Gutachten Friedrich Ebert Stiftung, Bonn, 1999.

UN Agenda 21: Programme of Action for Sustainable Development, Rio Declaration on Environment and Development, Rio de Janeiro, 1992.

USDA, Agricultural Baseline Projections to 2007, Staff Report No. WAOB-98-1, 132 pp., Springfield, USA, 1998.

Wambugu, F., Case Study: North-South-Transfer of Biotechnology to East Africa, in International Workshop on Biotechnology for Crop Production - its Potential for Developing Countries, Berlin, 9.-13. December, 1996.

Wilson, E.O., Der Wert der Vielfalt, Piper, München, Zürich, 1997.

World Resources Institute, Food and Environment Security Initiative, Washington, 2000.

Yudelman, M., Ratta, A. and Nygaard, D., Pest Management - The Expected Trends and Impact on Agriculture and Natural Resources to 2020, IFPRI, 2020 Vision Food, Agriculture and the Environment, Discussion Paper Series, Washington, 1998.

Further relevant references:

Arbeitskreis Evangelischer Unternehmer in Deutschland e.V. (AEU), Grüne Gentechnik - Vom ritualisiertern Streit zum sachorientierten Diskurs, Herbert Utz Verlag, München, 2000.

Carter, J., Africa Needs Western Agricultural Technology, in: International Harald Tribune, 06.11.1997, p.6, 1997.

Coates, J.F., Mahaffie, J.B., and Hines, A., 2025 Scenarios of US and Global Society Reshaped By Science and Technology, Published for Coates & Jarratt, Inc. by Oakhill Press, Greensboro, USA, 1998.

Cohen, J.E., How many people can the earth support?, W.W. Norton & Company, New York, London, 1995.

Diouf, J., Die Gentechnik kann den Hunger lindern, Interview in: Die Welt, 24. Juni 2000.

Döös, B.R., Environmental Degradations, Global Food Production, and Risk for Large-scale Migrations, in: Ambio 23/2, 124-130, 1994.

Doornbos, G., The Multifunctional Character of Agriculture and Land, PROSI Magazine 368, September 1999.

Graham-Smith, F., Population - the complex reality, The Royal Society, North American Press, London, 1994.
Friedman, T.L., The Lexus and the Olive Tree, Farrar Straus Giroux, New York, 1999.
Hobhouse, H., Fünf Pflanzen verändern die Welt, dtv/Klett-Cotta, 1993.
International Development Research Centre, International Plant Genetic Resources Institute, and Dag Hammarskjöld Foundation, The Crucible II Group, Seeding Solutions Vol. 1, Policy options for genetic resources: People, Plants and Patents revisited, Litopixel, Rome, Italy, 2000.
Juma, C., International Conference on Biotechnology in the Global Economy, Chair's Summary, Center for International Development at Harvard University, Cambridge, MA, USA,1999.
Kammen, D.M. and Hassenzahl, D.M., Should We Risk It? Exploring Environmental. Health, and Technological Problem Solving, Princeton University Press, Princeton, NJ, USA, 1999.
Kern, M., Gentechnologie und Welternährung, Brot für die Welt, Misereor, AGEH, KLB, Akademie Klausenhof: Symposium Juni 1999, Hamminkeln, Germany, 1999.
Kern, M., Bevölkerungswachstum, Welternährung und Welternährungssicherung, in: Gentechnik - Grenzzone menschlichen Handelns? Gesamtverband der Deutschen Versicherungswirtschaft e.V., Berlin, Kohtes & Klewes Berlin GmbH, S. 189-197, 1999.
Kern, M., Global Perspectives on Pesticides, Biotechnology and Seeds, 21st Annual Scientific Meeting of the National Academy of Science and Technology, Philippines, 7th - 8th July, 1999, Manila, The Philippines, 1999.
Lietzmann, K.M. and Vest, G.D. (eds.), Environment & Security in an International Context, Committee on the Challenges of Modern Society, Final Report No. 232, New York, 1999.
McRae, H., The World in 2020, Power, Culture and Prosperity: A Vision of the Future, Harper Collins Publishers, London, 1994.
Montanari, M., Der Hunger und der Überfluß, Kulturgeschichte der Ernährung in Europa, Beck'sche Reihe, Berlin, 1999.
Naisbitt, J.A.P., Megatrends 2000, Düsseldorf, Wien, 1991.
Persley, G.J. and Lantin, M.M. (eds.), Agricultural Biotechnology and the Poor, CGIAR, Washington, 2000.
Prante, G., Grüne Gentechnik im Pflanzenschutz: Die Situation, die Verantwortung, die Nachhaltigkeit, in: Symposium "Grüne Gentechnik in der Landwirtschaft - Die Zukunft hat schon begonnen", Grüne Woche, Berlin 19.01.1998.
Riviere, J.E., Why our food is safer through science?, Research Triangle Publishing, Inc., 1997.
Ross, H. and Tennant, D., A Definitive Guide to GMOs, Genetically Modified and Novel Foods in the EU, The Law and Technology of GMOs in Europe, Monitor Press, Sudbury, UK, 2000.
Sahai, S., The Bogus Debate on Bioethics, in: Biotechnology and Development, Monitor 30, 24, 1997.
Sautter, H., Die Ethik der Entwicklungshilfe und der Entwicklungszusammenarbeit (E+Z) 37/11, 288-289, 1997.
Serageldin, I. and Persley, G.J., Promethean Science - Agricultural Biotechnology, the Environment, and the Poor, CGIAR, Washington, USA, 2000.
Smith, L.C. and Haddad, L., Overcoming Child Malnutrition in Developing Countries: Past Achievements and Future Choices, Food, Agriculture, and the Environment, Discussion Paper 30, IFPRI, Washington, USA, 2000.
Stiftung Entwicklung und Frieden: Globale Trends 1998, Fischer Verlag, Frankfurt/M., 1997.
Thayer, A.M., Transforming Agriculture, C&EN April 19, 1999.
Trail, B., Globalization in the food industries? in: European Review of Agricultural Economics 24, 390-410, 1997.
Virchow, D., Conservation of Genetic Resources - Cost and Implications for a Sustainable Utilization of Plant Genetic Resources for Food and Agriculture, Springer, Berlin, 1999.
Wilson, E.O., Consilience - The Unity of Knowledge, Alfred A. Knopf, New York, 1998.
Zechendorf, B., Sustainable development: how can biotechnology contribute? TIBTECH 17, 219-225, 1999.