BIOTECHNOLOGY AND THE NEW INFORMATION TECHNOLOGIES IN AGRICULTURE: DEVELOPMENT, PROSPECTS, IMPACT AND ISSUES

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ABSTRACT

The article discusses developments and prospects for the application of biotechnology and information technology to agriculture, their issues and their impact on the agricultural production model in developed countries. It first sets out their different possible applications in the various sectors of agricultural production and their present stage of development. It then examines their potential impact, highlighting their ambivalence. Lastly, it deals with the new technologies faced with the changing demands made on agriculture (emphasis on product quality, environmental soundness, regulation of supply, social acceptability of the techniques used). The conclusion emphasizes that it would be desirable to steer directions of the new technologies towards a more sustainable model of development.

RÉSUMÉ

L'article discute des perspectives d'application en agriculture des biotechnologies et des nouvelles technologies de l'information, de leurs enjeux et de leurs impacts sur le modèle productif agricole. En premier lieu on présente leurs diverses applications possibles dans les différents domaines de la production agricole et leur stade de développement. Puis on s'interroge sur leurs impacts potentiels, ce qui met en évidence leur ambivalence. On réfléchit en fin aux potentialités des nouvelles technologies face aux modifications de la demande adressée à l'agriculture (qualité des produits, préservation de l'environnement, meilleure régulation de l'offre, etc). La conclusion souligne qùil serait souhaitable d'orienter les nouvelles technologies et leur utilisation pour permettre un modèle de développement plus durable.

A new wave of major innovations that could bring about major changes is presently beginning to spread to agriculture, as to other economic sectors: biotechnology and the new information technologies (data processing, electronic communications systems, automation etc.).

It occurs in a time when the type of agriculture practised in the last decades is called into question and when a new agricultural model seems to be needed[1] (Bonny 1997a). It is worth considering the new technologies in this light. In addition biotechnology, particularly genetic engineering, is the subject of controversy: so it seems useful to examine its possible effects. In this article, we outline the applications of the new technologies in agriculture and their stages of development (I); we then examine their possible impact and issues (II); and lastly, we analysed their potentialities in the light of changes in the demands made on agriculture (III).

The analysis set out here is based on the example of France, but it also applies, more broadly, to western Europe, Mediterranean region and some other developed countries.

However the state of development of biotechnology and the new information technologies is not so advanced in those regions as in the USA (Huttner, Miller, Lemaux 1995).

I - BIOTECHNOLOGY AND THE NEW INFORMATION TECHNOLOGIES (NITs): APPLICATIONS IN AGRICULTURE

Although biotechnology and the new information technologies have been much discussed over the past fifteen years, it will be useful to recapitulate their possible applications in agriculture and their present state of development before analysing their implications, in order to have an overall and comprehensive view of them.

1.1. Biotechnology

Biotechnology constitutes a new technological paradigm in that it represents a shift from the exploitation of inert matter that characterised the industrial revolution of the 19th century and the last agricultural revolution, to the exploitation of better known and internally[2] modified living matter. Man's use of living matter is of course very ancient, dating virtually from the emergence of agriculture some 10,000 years ago, but biotechnology represents a decisive step forward, a rupture. Living matter can now be modified from inside by gene transfer and genetic reprogramming, and we are beginning to understand its innermost processes; this gives a far greater scope for action than before, when we tried to tame living matter by more empirical means without really understanding physiological mechanisms involved. In the industrial revolution of the 18th and 19th centuries, mankind put "mechanical slaves" to work for him; the 21st century could witness

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(1) The agricultural production model corresponds to the underlying logic which leads production processes and ways of producing, i.e. to the main paradigm in production where it leads to certain technical and economic characteristics.
This concept of a "technical model" is fairly similar to the "technological paradigm" put forward by G. Dosi (1982, 1988) while the "production model" is closer to the idea of a "techno-economic paradigm" developed by Freeman and Perez (Perez, 1983; Freeman and Perez in Dosi et al., 1988).

(2) In conventional plant or herd breeding there is indeed an internal modification but at random: breeders don't know precisely which genes are transferred. In genetic engineering the transferred gene is known and has been studied, and above all it can come from any species (see below § 1.1.1.).

a bio-revolution, with "slave bacteria" and "worker microbes" at the service of mankind (i.e. increased use of micro-organisms to carry out certain processes), genetic engineering and development of plant-based chemistry in place of petrochemistry. This increasing use of biological techniques in place of chemical or mechanical means, and of renewable substrates in place of fossil fuels, could gradually make agriculture and other economic activities more renewable and perhaps help towards a more sustainable form of development, at least under certain conditions (Bonny 1994).
Definitions of biotechnology vary in their breadth of application. Some include the empirical use of micro-organisms for fermentation, as has been done for thousands of years to produce bread and wine; others include only one aspect of the new biotechnology - genetic engineering. Taking a broad but literal definition of biotechnology, one can indeed consider that human societies began to practice it thousands of years ago when they shifted from hunting and gathering to farming and herding. Here, however, we shall be considering the new generation of biotechnologies based on the breakthroughs of recent decades in genetics, molecular biology, microbiology, enzymology and physiology.

1.1.1. Applications of biotechnology in agriculture

They seem very great. Biotechnology concerns many branches of the economy: pharmaceuticals, medicine, agriculture, the food industry, aquaculture, energy, chemicals, environment, etc. At present, the most important markets are those for medicines and diagnostic kits; but the highest rate of growth is expected in the coming years in agriculture (Shamel, Keough 1994, 1995). Various biotechnologies can be used in agriculture.

• Micropropagation involves regenerating and multiplying an entire plant from a fragment of one - a method long used in agriculture for plants propagated from suckers or tubers. Biotechnology has made it possible to extend this method to numerous species; apical meristems (i.e. terminal buds) are cultured in vitro; from these, numerous embryos and plantlets are produced, first in test tubes (whence the name "vitroculture") and then in the field. This has a number of advantages: (a) one can produce large numbers of clones of a useful or exceptional plant, e.g. a variety resistant to certain diseases; (b) the use of apical meristems ensures virus-free plants; (c) one can select useful variants in this way; and (d) one can quickly produce a large number of plants at usually low cost.

• Genetic engineering is doubtless one of the most remarkable and innovative aspects of biotechnology; for some, it heralds the coming of the "age of genetics". By genetic engineering one can transfer a gene from one species to another and so considerably increase the possibilities for genetic improvement. This was traditionally achieved by crossing and was therefore limited by the sexual reproduction barrier: one can only cross plants or animals of the same species. Moreover, results are extremely unpredictable since half of each parent's traits are transferred, in a random fashion, to each offspring. With gene transfer, the possibilities are theoretically immense, since one can transfer from one species to another a single gene whose properties are known, and insert into a plant, animal or bacterium a given gene from any other organism, regardless of barriers between species and even kingdoms. In practice, of course, it is not always easy to identify useful genes and transfer them so that they are expressed in the new host, especially as complex traits such as yield depend on a combination of many genes and, so far, we only know how to transfer a few at a time. In addition the position effects of gene insertion are still not thoroughly understood.
Another major advance is plotting the gene maps of plants and animals, making it possible to locate, on the chromosomes, genes that play a part in a given trait. This should facilitate breeding geared to specific objectives. It also makes it possible to characterise genetic variability better, indicating the endangered varieties or breeds that need to be conserved.

• In agriculture and in medicine, biotechnology also has useful applications in **diagnostic methods**. Diagnostic kits based on monoclonal antibodies or nucleic acid probes have already been developed; the farmer or technical expert takes samples to be analysed by these means. In this way, for example, one can:
/ Determine the presence of a disease in a crop. These kits allow early detection, before symptoms are visible to the naked eye, so that chemical applications can be adapted to the diseases actually present; one need no longer choose between systematic, broad-spectrum, precautionary spraying and spraying too late.
/ Identify contamination of the harvest by mycotoxins (natural toxins secreted by microscopic fungi).
/ Detect pathogenic plant viruses, so enabling seed producers to identify resistant varieties; it can also be used for border checks to ensure export or import of healthy plants and avoid cross-border propagation of certain diseases.
/ Determine certain characteristics of produce on delivery.
/ In livestock, pregnancy testing and diagnosis of illness enable the farmer to respond earlier. Moreover, it should be possible to sex embryos before transfer to the recipient cow, using a molecular probe that identifies the Y chromosome.

• Biotechnology also provides possibilities for developing effective vaccines with less risk of pathogenic effects since they contain only the antigen responsible for the immune response and not the entire micro-organism; as a further advantage, they make it possible to differentiate between infected and vaccinated animals.

• Biological engineering is also a thriving field of research in animal reproduction: *in vitro* fertilisation, embryo transfer, cloning (i.e. reproduction of identical copies of an animal), etc.

1.1.2. Stages of development and fields covered by different applications

The different spheres of biotechnology mentioned above are at different stages of development:

• *in vitro* vegetative propagation of some species is already quite commonly practised throughout the world, including the developing world. Examples are ornamentals, fruit trees, food crops, date palm and oil palm.

• Gene transfer is already used to reprogram organisms and have them produce substances useful to man at quite low cost. The other applications of gene transfer concern plant and animal breeding, with the creation of transgenic plants and animals into which a foreign gene has been inserted to obtain such useful characteristics as disease resistance. A great deal of research and experiment is going on around the world in this field, and the first transgenic plants came onto the market in the United States in 1994. At the end of 1995 (i.e. at the end of the first decade of field trials) 3647 field trials of transgenic plants have been conducted in more than 15,000 sites in the world (James & Krattiger 1996). At least 56 crops have been concerned, but in a different frequency: corn, rapeseed (canola), potato, tomato and soybean represent almost three-quarters of the field trials. The most frequent traits introduced by transgenosis are

— herbicide resistance (1450 field trials),

— agronomic characteristics (like new hybrids) or product quality (806),

— insect resistance (738),

— viral resistant (466),

— fungal resistance (109).

The traits introduced by transgenosis are gradually evolving: in the first years of the fields trials, herbicide tolerant plants were the most frequent, but now the number of traits concerning insect resistance, product quality or viral resistance is growing. Great hopes have been pinned on gene transfer, although commercialisation of transgenic varieties has been delayed in some countries owing to acceptability problems. In the USA there are already about 15 modified plants authorized to be commercialized at the end of 1996, and in 1996 several hundred thousands of hectares of transgenic cotton (resistant to an insect), transgenic soybean (resistant to the herbicide glyphosate) and transgenic corn (resistant to European corn borer) were cultivated (James & Krattiger 1996).

• Diagnostic kits for plant and animal diseases or for determining quality have begun to appear on the market over the past few years.

• New vaccines are also becoming available commercially.

• As regards biological engineering, new technologies in animal reproduction (embryo transfer etc.) are already in use, though to a limited extent owing to their high cost. Others, such as cloning, are still at the experimental stage.

For research scientists, biotechnology is first and foremost a set of new means to study living organisms. It

Table 1 ***Biotechnology applications in crop production.***

	Stage*
● Plant breeding:	
• New possibilities for genetic improvement by gene transfer, protoplasm fusion (in the cell). Possibilities for obtaining:	E, A, U
— varieties resistant to herbicides, pathogenic agents, insects, viruses	
— varieties more tolerant of drought, salt, cold and metals	
— varieties suitable for long storage (tomatoes)	
— varieties with higher levels of protein, amino acids, etc.	
— varieties suited to particular industrial uses (modified sugars, fatty acids, etc.)	
— low-nitrate varieties	
— varieties with new ornamental traits	
• Faster selection, making it possible to develop new varieties faster (e.g. with gene maps and haplodiploidization)	E, A
• Multiplication of identical copies of useful plants (cloning, micropropagation)	U
• Increased possibilities for creating hybrids	A
● New and faster ways of obtaining healthy plants: vegetative multiplication *in vitro*, production of artificial seed (by enveloping plant embryos in a protective, nutritious coating)	U, E
● Fertilisation	
• Developing synergy between crops and micro-organisms: spraying bacteria onto crops, inoculating roots with bacteria or soils with microscopic fungi, to stimulate plant growth	E, A
• In the longer term, possibility of obtaining plants capable of fixing atmospheric nitrogen	E
● Pest and disease control	
• Development of resistant varieties by gene transfer or *in vitro* culture	E, A, U
• Virtually instantaneous diagnosis using kits (monoclonal antibody probes, nucleic acid probes)	A, U
• Biological pest control using natural enemies of pests and parasites	U, A, E
● Frost control	E
• Control of ice nucleating bacteria (i.e. bacteria that facilitate ice formation in the plant) either with antibacterial agents or by biological control, substituting non ice-nucleating bacteria (transgenic or otherwise)	
• Transfer of anti-freeze genes from other organisms	
● New ways of obtaining some products: production of pharmaceutical molecules or other substances (vanilla, pyrethrum, alkaloids, some fatty acids, etc.) from modified plants	E
● Fast determination of the quality and composition of a substance (protein levels, presence of mould, pesticide residues, etc.)	U, E
• Determination of the variety a seed belongs to, using genetic "identity cards" of varieties	

Stage* U: Already in use
A: First applications available commercially
E: Experimentation and research stage

Table 2 ***Biotechnology applications in animal production (for stage of development, see above)***

	Stage*
● Faster breeding methods	
— Using probes, one can discover an animal's genetic characteristics, at the molecular level, at birth. This way, breeding programs can be accelerated by eliminating the time lost waiting for testing. Gene mapping promises the same kind of advantage	E, A
— With embryo transfer and cloning, one can increase the progeny of a particularly promising animal	Transfer: A Cloning: E
— Deep freezing of embryos allows storage, transport and trade of genetic material in a compact form and with no risk to health	A
● Genetic improvement by gene transfer. Research is under way on:	E
— disease-resistant animals,	
— sheep with a higher wool yield,	
— pigs and poultry that can synthesise certain essential amino acids,	
— alteration of milk composition (cheese-making quality, lactose level to improve digestibility)	
— poultry genetically programmed for leanness,	
— fast-growing, transgenic, triploid fish (i.e. having three copies of their chromosomes)	
— improving growth in certain species by transferring growth hormone	
● Feeding and feed additives	
— use of probiotics, i.e. microbes and enzymes added to animal feed to improve their assimilability or the digestive efficiency and health of the animal	E, A, U
— use of growth hormone (somatotropine) obtained by genetic engineeringto increase milk yield (BST), or produce leaner, faster-growing pigs (PST)	A, U (BST) E (PST)
— better understanding of animal nutrition and nutritional requirements (and hence better adaptation of rations and reduced nitrogen excretion); use of substances capable of modifying microbial fermentation in the rumen (e.g. to reduce methane production)	A, E
— feed additives capable of reducing pollution by excreta (reducing the quantity of excreta)	A, E
● Pathology	
— diagnostic tests for fast, precise identification of viruses, pathogenic bacteria and pregnancy, using monoclonal antibodies or molecular probes	A, U
— new vaccines containing only the antigens responsible for the immune response	A, E
— disease-resistant transgenic animals	E
● Reproduction	
— out-of-season reproduction (oestrus and parturition on the desired dates)	U
— embryo transfer, increasing the number of progeny from the most valuable animals	A
— deep frozen embryos for easier transfer, export of livestock in reduced form, establishment of embryo banks to save endangered breeds	A
— sexing (allowing choice between male and female embryo for transfer)	A
— cloning: makes it possible to produce identical copies of particularly promising animals	E
● Applications in medicine	
— transgenic animals can be used as living fermenters to produce rare proteins of chemical or pharmaceutical value in their milk ("gene farming"), e.g. blood factors for treating haemophilia, alpha-1-antitrypsin, interleukin or transferrin	E, U
— transgenic animals could produce "humanised" organs that could be grafted into humans	E
— genetically modified animals for use as experimental models for studying the development and possible treatment of certain diseases.	U, A, E

Stage* U: Already in use
A: First applications available commercially
E: Experimentation and research stage

may produce unexpected but extremely important spin-offs: for example, an understanding of certain fundamental developmental processes in plants or animals may open the way to major applications.
In **tables 1** and **2**, we have tried to indicate, in the present state of the art, some foreseeable biotechnology applications in crop and animal production.
Taking the long view, it certainly looks as if the industrial revolution could be followed by a bio-revolution, but this will take place gradually and doubtless, in the early stages, slowly. Broadly speaking, the history of technical innovation shows that the time lag between the first discoveries and their widespread application is often long, and the new generation of biotechnologies is very recent.

1.2. The new information technologies in agriculture: the case of France

The term "new information technology" (NIT) covers a certain number of technologies based on rapid, automatic information processing: computers, electronic communications systems, electronics in farm machinery, robots, remote sensing. **Computers** (on the farm or available for use at a management centre) are directly used by a fairly small proportion of farmers. They are mainly used for accounting and financial management of the farm, secondly for technical and economic management of particular crops or livestock, and more rarely for commercial management (software for ordering and billing, used, in particular, by wine growers and horticulturists to manage sales, stocks and customers). More recently, software packages have appeared on the market for strategic management of the farm environment issues, or crop acreage declarations under the new CAP. Electronic communications systems have been used for a decade to differing extents in different parts of France. This is due to a French national policy: all telephone subscribers could receive free of charge a terminal "Minitel" which gives access to a French national data communications network. These systems are much used in Brittany, for example, where farm-related organisations offer numerous services by this medium. Farmers use them to communicate with certain services of the Chambers of Agriculture or the stock farmers' co-operatives (e.g. for ordering artificial insemination), for weather forecasts and crop health forecasts (information on the likelihood or prevalence of particular crop pests and diseases), for information on farm prices and markets, and to link up with their banks. A growing number of farmers have also acquired fax machines for fast reception of weather forecasts and pest and disease warnings, crop spraying advice, etc. But for the moment internet services are still rather rarely used by farmers.
Electronics, mounted on equipment or incorporated in

buildings, can improve the efficiency and quality of farm work. In the longer term, the trend is towards more fine-tuned, targeted application of inputs according to the local needs of the crop as assessed by sensors. This is already in operation on some farms for irrigation, and is at the research stage for fertiliser and pesticides. In greenhouses and livestock housing, electronics can automatically control temperature, light and atmospheric humidity according to the needs of animals and plants. Various robots for agricultural use are currently at the research stage around the western countries, but they are very rare in real farms in France. Attempts are also being made to automate livestock housing management in line with parameters automatically measured on each animal (feed intake, daily liveweight gain, milk yield and quality, etc.). Apart from agriculture, the trend is towards robotisation of repetitive and thankless tasks in the food industry.
Remote sensing makes it possible to establish certain characteristics of vegetation from a remote source (usually a satellite). Although applications are still fairly limited, the potential is great, e.g. for land use analysis; estimating the area under a particular crop; information on the existence and scale of drought; harvest forecasts, especially for extensive, low-yield crops (this is used in international economy); and monitoring conditions in forest areas, deforestation especially.
On a planet-wide scale, the world-wide electronic information exchange networks embrace harvest forecasts, climatic events, quantities of farm commodities bought or sold, political trends, etc., and may have a considerable impact on commodity markets.
The new information technologies thus have applications in most farming activities. Depending on the case in hand, they may be applied at different levels - from a single field or farm holding to the entire planet. At the national and regional levels, the public authorities can use remote sensing and geographical information systems to manage the territory for which they are responsible. Beside the NITs, agriculture uses more and more information in the form of knowledge to be acquired and technical or economic data to be gathered and processed. Information makes it possible to match inputs to production needs, and output to the needs of the market, while helping to reduce waste and pollution. However, a more detailed examination of the impact of the new technologies is required.

II - Implications for agriculture: possible impact, questions raised

2.1. Technology is often double-edged

The possible impact of a technology depends on the use that is made of it. This is the case for biotechnology which may have very different effects. It may, for example,
— reduce the amount of pesticides used while increasing seed costs;
— either diminish genetic diversity by cloning and micropropagation, or increase it through gene transfer, gene banks, embryo transfer used to safeguard endangered breeds, and better knowledge of the different genotypes a gene map allows for;
— either produce high-quality products (by means of diagnostic kits and gene transfer to endow products with particular characteristics), or pollute the environment if transferred genes are accidentally transmitted to other organisms;
— contribute to cleaner farming (using less pesticide in particular), but by means of gene transfers from one organism to another, which some people regard as unnatural;
— enable medicine to treat formerly incurable diseases by gene therapy and obtain therapeutic proteins free of viruses, while agricultural applications release GMOs (genetically modified organisms) into the environment that may endanger some ecosystems;
— either improve the production capacities of developing countries and enable them to meet their own food needs more effectively, or increase the gulf between North and South owing to (a) the sophistication of some techniques, (b) the patenting of living matter and (c) loss of markets by some countries if the agricultural products they now export come to be produced in the North by biotechnology;
— either make technology more "natural" or further "artificialise" living matter.

2.2. The potential effects of biotechnology

They are very varied, depending on the objectives set by its promoters. One can imagine:
— qualitative product improvement (e.g. in terms of composition) according to the intended end use, adapting products to different types of consumer or different industrial uses. Current research aims to produce less fatty foods, milk enriched in lactoferrin (better for children), oils containing particular fatty acids for particular uses (which should boost the development of plant-based chemicals in place of petrochemicals), and biomass containing less lignin, e.g. for the paper industry;
— increase in agricultural production or a more efficient one. Resistant plants should make it possible to limit production losses, which are still very high in some cases (Oerke, Dehne 1997), or to use less inputs for a given volume of output. Agricultural production could also increase with varieties more tolerant of drought, salt or metals;
— changes in the volume and nature of goods purchased by farmers: in theory, farmers should use less chemicals, but they will have to buy seed more often,

and seed is likely to be more expensive.
— theoretically, pesticide use should decline if resistance to pests and diseases is developed. But the most common type of gene transfer experiments so far have focused on transferring weed-killer resistance to crops: such varieties would be cultivated using the herbicide in question and all weeds will be destroyed. Apart from the experimental aspect (this type of gene transfer was used as a research model as it was easier than other types), the advantage might be easier weed control. This might also be less damaging to the environment, provided the weedkiller used were of particularly low toxicity. For the agri-chemicals firms, it is also a way of protecting their markets. Despite the large number of herbicide-resistant transgenic plants that are technically nearly ready, the volume of weedkiller used should diminish. But the question remains as to what types of herbicide will be used, as their impact on the environment varies considerably. Although low-toxicity weedkillers are usually chosen, some, like bromoxynil, are controversial in this respect; moreover, if a rapidly biodegradable weedkiller is used, it must be applied several times, which could increase the total quantity used. Repercussions also depend on the crop concerned and the case. So maize resistant to glufosinate (a low-toxicity herbicide) makes it possible to avoid using the more polluting current product, atrazine, which would be an advantage. But herbicide-resistant oilseed rape and sugar beet arouse some concern, as these plants can cross-fertilise with wild plants of the same family (Mikkelsen et al. 1996, 1997), and this might in the end lead to herbicide-resistant weeds. Farmers could encounter some difficulties in managing their rotations, for example with volunteer seedlings of herbicide resistant rapeseed. In addition with an increased use of Bt proteins (which make varieties tolerant to insects), insects might develop resistance to Bt, an interesting molecule which would lose its interest. Two or three different types of insect resistance must be introduced simultaneously in the plants to avoid this resistance development;
— closer relations between farming and agri-business, both upstream and downstream, e.g. (a) if payment by quality spreads as quality can be more precisely assessed, (b) if farmers sign contracts to grow single-purpose varieties (the firm then decides on the seed and a particular set of cultivation techniques, against guaranteed purchase), or (c) if using a particular seed variety means using the associated herbicide or other input. By contrast, one could imagine agriculture achieving greater self-reliance by using resistant varieties or on-farm diagnostic tests for diseases. In general, however, the likeliest trend is towards greater dependence on industrial firms on the supply and demand sides;
— more patents on living matter. To ensure return on investment, firms in this sector want to protect their inventions by patent, as has long been the practice for industrial procedures and objects. Until recently, plants and animals could not be patented; there was a simpler system of plant breeders' rights on new varieties which, while ensuring the breeders' remuneration, also guaranteed free access to the genetic resource to create further new varieties. Patents in this field may well put an end to such free access. Third World countries may have to pay dearly for seedstock of species for which they are the reservoir of genetic diversity. Farmers may also have to pay royalties to sow selected seed from their own previous harvest. Action has been taken by various protagonists on this issue, either demanding the right to patent living things to get compensation for their long-term and extensive R&D efforts and investments, or opposing it. Opponents stress that genetic resources, which are part of humanity's universal heritage, should not be privatized and that developing countries should receive some royalties for the use of their genetic resources and should keep free access to them for research and in biotechnology transfer back from the North. In addition genetic engineering is only one stage in the breeding of a new variety, which requires a good deal of agronomic research over almost ten years or so: this conventional breeding work must not be ignored. A balance must be found between free access to genetic resources and return for the companies which have developed gene transfers;
— in environmental terms, biotechnology could be beneficial, as it "naturalises" technology (i.e. it would lead to greater use of the possibilities of living things and less use of chemicals); moreover, the increase in biological and ecological knowledge may lead to greater friendliness to the living world. But there are dangers: genes transferred to certain plants or organisms could be passed on in an uncontrolled manner to other interfertile plants and organisms, leading for example to invasive new weeds (Deshayes, 1993; Rissler & Mellon, 1996; La Recherche 1994; Mikkelsen et al. 1996, 1997; Paoletti & Pimentel 1996). Some also think that, with biotechnology, mankind's mastery and possession of nature could reach a dangerous stage it is risky to artificialise living matter too much by modifying the genetic heritage and inserting genes from one organism into another (Giampietro, 1994; Wills, 1994). Others stress the advantages of biotechnology, the possibility of moving on to a new stage of technical progress with plants better able to resist pests and disease and better suited to different uses. The new genetic revolution seems indispensable for the coming century, given the need to feed a fast-growing world population while respecting the environment; under certain conditions, biotechnology could help make development more sustainable (Mannion, 1995).
The effects of a technology depend on the direction given to it, and there is much uncertainty as to the ori-

entations that would be given to biotechnology. In the first place, scientifically and technically, biotechnology is in its earliest stages, still needing much research; it could have unexpected developments or repercussions. In other spheres too, there is great uncertainty: (a) acceptability to public opinion, which has an impact on the regulations and authorisation procedures introduced; (b) the strategies of the economic agents involved, particularly the specialist firms and major agrichemicals corporations that have invested in this sector (c) the involvement of public sector research in the different countries and in the international research agencies, compared to the strong involvement of private firms over the past decade (Busch et al., 1991).
It is often said in order to legitimize biotechnology that it is essential for feeding the growing human population in the next century. However R&D in this area is carried out mostly by private companies which are directed towards rich markets rather than towards the need of non-solvent populations. Admittedly, development agencies and international organisations (like the Research Centers of CGIAR[3] are trying to develop R&D more directed toward the needs of developing countries and tropical agriculture. But they often suffer from some lack of financing. From 1986 to 1995, 91% of the field trials of transgenic plants have taken place in developed countries (53.5% in the USA) and only 8% in developing countries : 0.7% in Africa, 1.7% in developing Asia, 5.6% in Latin America (James & Krattiger 1996). Therefore better food security thanks to biotechnology should not be taken for granted (Bonny, 1996b; Bonny 1997b).

2.3. The new information technologies and increased use of information

They may also have a range of different effects on the agricultural production model. They could lead to
— a better matching of inputs (fertilisers, pesticides, stock feed, water, etc.) to the needs of crops and herds. This would be due, in particular, to a more precise knowledge of plants and animals requirements at their different stages of development, and to the use of diagnostic tools and sensors to evaluate water and nitrogen requirements or disease risk. It also requires appropriate methods for applying inputs just when and where they are needed (targeted applications). This finer tuning of inputs to the needs of plants and animals makes for greater production efficiency and avoids pollution. But for farmers to adopt such methods, the new technique must cost less in time and investment than the amount saved on inputs and/or there has to be a strong incentive to reduce pollution;
— lower energy consumption per unit of product, since regulatory mechanisms can improve energy efficiency; finer tuning of input applications to crop requirements also tends this way (Bonny 1993). More generally, information is a way of reducing energy expenditure because it is negentropic. But this assumes that it is cheaper than energy. Today's low prices hardly encourage energy saving, though it seems likely, in view of the growth in world consumption and of the unequal distribution of oil reserves, that oil prices will rise within the next decades;
— faster action in matters of crop protection or economic decisions, and greater vigilance, may make users of the new technologies more competitive;
— better working conditions thanks to automation (e.g. tractor driving will become less arduous) and a slight reduction in working hours;
— the NITs are adopted first and foremost by farmers with a high level of education (especially for computers). As a result, these technologies seem likely to strengthen disparities between farm holdings;
— the NITs may allow farmers to handle larger farms or more livestock, which increases the productivity of labour and may help cut production costs, but also reduces jobs in farming. However, farmers can increase the value they produce by other means than increasing quantitative output - improved product quality, home processing and direct sales, introduction of new activities, especially services (care of the countryside and rural heritage, neighbourhood services, etc.); this may help maintain agricultural employment. Teleworking could also contribute to create some jobs in rural areas, avoiding their abandonment;
— agricultural work is becoming more abstract; there is rather less direct contact with plants and animals and more mediation by machines. In this respect, farming is moving away from town dwellers' expectations of the countryside and their bucolic image of the farm. On the other hand, some NITs could give farmers more time to provide different types of services (e.g. care of the environment, farm-based tourist services, neighbourhood services, etc.) and facilitate their management;
— standardisation of production styles and imposition of standards are likely to increase...
— on a world scale, the NITs mean that information circulates more rapidly. This could accentuate farm price fluctuations and lead to speculation, so worsening market instability;
— the new technologies allow greater control over a large body of information and data. Who will have control? Sometimes farmers, for whom computers will mean a better understanding of certain flows, greater vigilance, reassurance and a demand for more precise advice. Sometimes a community or an authority (e.g. with remote sensing for better land use management or closer control of farmers' applications for subsidies or

(3) CGIAR: Consultative Group on International Agricultural Research.

compensation payments). In some cases, it could be a firm or nation using NITs in the trade war (or, indeed, outright war).
We must beware of the technological mirage. Computers haven't spread to the farms as fast as some actors had anticipated. In addition some of these sophisticated technologies are costly or insufficiently reliable (farmers dread a breakdown!). While they open up some interesting possibilities, such as a better match between inputs and crop requirements or less arduous work, they could also have more ambivalent effects. In addition availability and great amount of data are not sufficient by themselves: the issue is how to use them wisely. For example new electronic devices on combine harvester allow to know crop yields in each area of the plot; but it is rather difficult to deduce from that the best practices for the following crop; however, it could be an interesting pointer for the farmer.

III - The new technologies and demands made on agriculture

Demands made on agriculture have changed and are changing. Society is putting more and more emphasis on product quality, environmental soundness, regulation of supply, social acceptability of the techniques used; but competitiveness remains essential. Can the new technologies lead to those trends? It is needed to take into account that the development and directions of technology are influenced by many different actors and factors, particularly by suppliers, customers, social pressures, competition between corporations, etc.

3.1. Increasing emphasis on quality

If quality has become a leitmotiv, it has actually several meanings and refers to different aspects for different actors in the chain: product composition, absence of residues, flavour and aroma, bacteriological quality, homogeneity, appearance, etc. As an objective for the products of the farm, depending on their use, it refers mainly to their desirability for different customer types: processors, manufacturers, distributors, different consumer categories. Even consumers do not all share the same desiderata: some look for cheapness, some for quick preparation and cooking, others for local produce with the flavour of bygone country life, others for health value, others for "natural" products, etc. Biotechnology can improve quality in the sense of product composition, taste and flavour. On the other hand biotech opponents consider genetic manipulations as a dangerous deterioration in quality because of the transfer of foreign genes from other species, and because of the potential risks of toxicity and allergenicity of some genetically modified products. As for the NITs, they could increase product quality (particularly concerning residues) by more precise applications of chemicals and faster action for treatments.

3.2. Increasing concern for the environment

The companies involved in biotechnology or NTIs present them as particularly environmentally sound. For example, they could lead to less chemical applications; biotechnology can be used for bioremediation, and could increase agricultural yields leading to less deforestation or use of fragile soils to extend crops. On the other hand a lot of people are worried about some consequences of genetic engineering: according to their position or interests, they fear the transgression of species barriers, the risk of unexpected ecological damages, the spreading of new genes to weeds, the risk of development of resistance to Bt (if there is a large acreage of insect tolerant plants having genes coding for Bt). If biotechnology enables increasing knowledge of living matter, this one is somewhat reductionist and that could be a danger: a better knowledge of the whole plants and animals, of the ecosystems, of the agricultural production systems, of the social systems is also needed to increase or improve agricultural production, particularly in the developing countries.
If the new information technologies could have environmentally sound effects, particularly as regards input use, they could also lead to a standardisation of production styles and an imposition of standards leading to a loss of some local peasant knowledge and local varieties, which were often suited to local conditions.
To sum up, we could say that the trend affecting the environment depends on technology management and risk management. While the considerably increased power of mankind over nature entails greater risk, it can also reduce risk. Operations on the farm are better targeted and more appropriate, and mankind now has a sufficiently detailed knowledge of life processes to be able to take them into consideration. Advances in knowledge and social pressure could lead to work more in harmony with nature rather than against her. But this trend should not be taken for granted, particularly if it might affect short-term profitability!

3.3. Social acceptability of different technologies

It is also playing an increasingly important part. Biotechnology, genetic engineering especially, is not seen as fully acceptable, at least in western Europe. An opinion poll carried out by a Concerted Action of the European Commission in the different member countries shows that genetic engineering in agriculture is considered as potentially useful, but also risky - particularly for food production, crop plants and research animals; on the other hand genetic engineering for medical applications is better accepted (Eurobarometer, 1997). "The pattern of results across the six applications [...] suggest that perceptions of usefulness, riskiness and moral acceptability could be combined to shape overall support in the following way. First, usefulness is a precondition of support; second people seem prepared to accept some risks as long as there is a perception of usefulness and no moral concern; but third, and crucially, moral doubts act as a veto irrespective of people's views on use and risk" (Eurobarometer 1997). Protest movements have emerged, especially since town dwellers dream of a bucolic rural world when farming is becoming an ever more hi-tec business. The mad cow disease increased dramatically this suspicion in 1996 in Europe. Some people are worried about the dangers of manipulating nature and breaking through certain natural barriers as illustrated in the film *Jurassic Park*. For many scientists, on the other hand, there is no reason to suppose we are running more risk with a closely-studied gene introduced by genetic engineering than with several dozen poorly-understood genes introduced by the traditional breeding methods practised for thousands of years (though only with plants and animals of the same or very closely related species). For researchers, gene transfer from one species to another does not seem counter to nature because the genome of a species is made up of pieces found in other species, genes can be naturally transferred if a virus is integrated, and the genetic heritage of living species changes naturally over time (though very slowly). Moreover, in most countries, authorisation is required for genetic engineering experiments, whether in the laboratory or in the field, and for marketing the products. But there are also socio-economic dangers, e.g. in connection with patenting living matter and the increased marginalisation of some non solvent developing countries, not to mention, as with nuclear power, the use of a new technology as a weapon of war (bacteriological warfare) or the introduction in some countries of techniques that may be dangerous unless proper precautions are taken (Bonny 1996a).

As regards the new information technologies, here too, acceptability is relative.

Some think they will favour farm expansion and therefore mean fewer farms and farmers, which seems somewhat untimely at present in many western countries because of their high rate of unemployment and of abandoned agricultural areas.

In addition they also widen the gap between those who have the technology or the information and those who do not. If some people see NITs, precision agriculture, computerisation, etc. as great advances, others have some reticence because this corresponds to an abstract knowledge without less direct contact with plants, animals, fields: this virtual knowledge could be reductionist and poor.

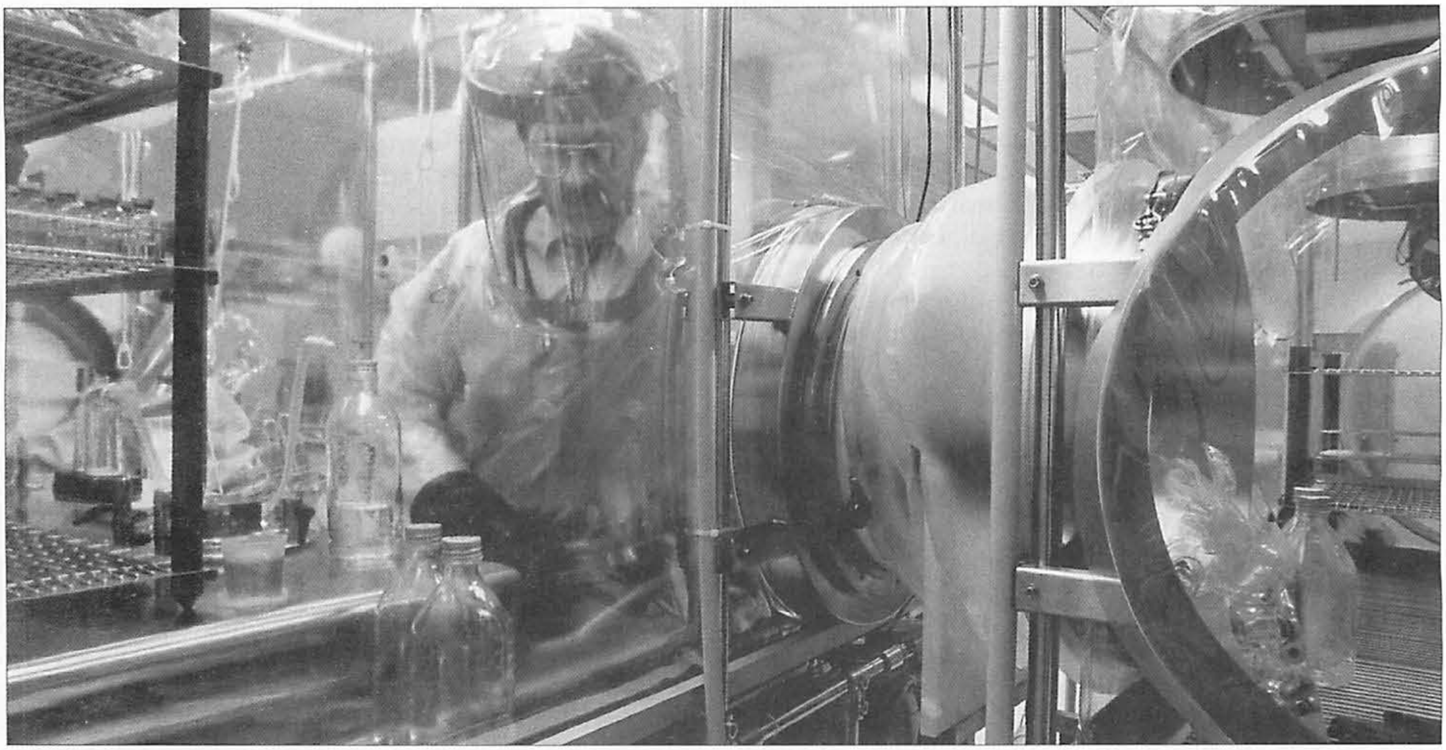
One important problem also is the use of all information and data potentially available; generally speaking information and knowledge are an important source of power which can be used for different purposes, so vigilance is needed.

3.4. Better regulation of supply

Agriculture must adapt to demand, but demand is varied and changeable. Agriculture must therefore be flexible as regards quality and, given the uncertainty of world markets, quantity. Some new technologies can foster such flexibility by enabling farmers to acquire information and make adaptive changes much faster than before. Another aspect is the diversification of the functions performed by agriculture: some farmers will mass-produce cheap products for food, chemicals or energy; others will focus on produce of high organoleptic quality, highlighting the place and method of production; others will target small market niches (e.g. rare plants or animals); others again will provide services such as tourism, on-farm accommodation, care of the landscape, nature conservancy, etc. Biotechnology could be a way to diversify agricultural production, for example with chemical or industrial or pharmaceutical molecules produced in plants and with the development of plant chemistry instead of petroleum chemistry. Biotechnology could contribute to diversify production according to region and potentiality, and to satisfy the different demand sectors and groups. On the other hand better regulation of agricultural supply seems very uncertain because of the risk of price fluctuations and of speculation in agricultural markets due to information and rumors. In addition the agricultural biotechnology industry is more and more dominated by a few companies, which leads to some standardization even if (and especially if) these companies seek to diversify their products. The new technologies increase the risk of strengthening disparities, and the marginalisation of certain groups or countries leads to a loss of diversity.

CONCLUSION

Biotechnology, particularly genetic engineering, is the subject of controversy, that's why we sought to present in this paper some aspects of its development, prospects, impact and issues. This paper focused on the potentialities of the new technologies, not on the strategies of involved actors. Examining the impact of technology as we have done here does not mean adopting a deterministic viewpoint; a new technology does not appear like a *deus ex machina* to change society. The development and orientation of technology is influenced by many different actors and there is a strong interaction or hybridisation between the social and technical aspects that shape technology. General socio-economic tendencies and particularly the strategies of the various actors involved may steer technological developments in different directions. It seems therefore useful to have a better knowledge of the potentialities of



the new technologies: this could help to have more influence on their directions. The new technologies may contribute to a gradual shift from a technical system based on the use of mechanical or chemical processes and fossil fuels to a new system based more on the use of life processes and information. Thus some chemical methods could be replaced by biological methods: transgenic, disease-resistant plants in place of pesticides; associations with bacteria or fungi to foster plant growth partly replacing chemical fertilisers. This does not mean a decline in the role of the agri-chemicals corporations that supply farmers with their inputs: they will take on a wider range of functions and products (they have been investing heavily in biotechnology) and new services (e.g. advisory services). Agriculture could be more fine-tuned, with inputs more precisely adapted to the needs of crops and livestock and better targeted, better informed farmer intervention, which should reduce pollution. Examples are nitrogen balance method for fertilisation; diagnosis and forecasting of diseases; better regulated spraying; application of fertiliser, plant protection products and irrigation guided by evaluation of requirements in each field (as a whole and locally). For stock feeding too, the search is on for finer tuning of protein supply to the animals' needs, a step which could reduce nitrogen excretion. The current aim is to apply the right dose at the right moment rather than systematic precautionary treatment in advance insuring against risk. Through promotion of a public commitment and a technical mechanism to mitigate farm chemical pollution, precision farming seems to legitimate chemically-based agriculture in an era of rising environmentalism (Wolf, Wood 1997). However other way than precision farming could be promoted, such as integrated farming which is based more on farmers' observations than on sensor records.

The new technologies seem double-edged, they can have positive effects but other more mitigated, or even negative (Bonny 1997c). Their impacts depend on the goals and the ways they are used in. A number of organisations have attempted *ex ante* assessments of biotechnology or the NITs (cf. OECD, 1989, 1992; World Bank, 1990; United Nations, 1992; parliamentary technology assessment units e.g. OTA, 1992). Articles have been published on biotechnology in large numbers (see for example the Bibliographies published by the Biotechnology Information Center of the USDA National Agricultural Library). There has been also an attempt to apply the precautionary principle with the regulation of genetic engineering for laboratory experiments, field trials, and commercialisation. However uncertainty remains high. The acceptability of genetically modified food is not presently established in Europe; in other countries also a number of NGO or associations express real concern. The new technologies appear actually risky not only because of their environmental effects, but also because of their economic impact; in addition they give rise to some moral doubts (Deshayes, 1994). However is too early for judging genetic engineering. This technology is still in its earliest stages and could have unexpected repercussions and advances. The first applications put on the markets (herbicide and insect

resistant plants) are not typical of the various developments that genetic engineering can have in mid and above all long run.
The power of this operation tool on living matter leads to the issue of its mastery. Even if mankind remains powerless against nature in some spheres (e.g. climatic hazards or earthquakes), it is now not so much a question of controlling nature as of controlling the mastery of nature, to quote Edgar Morin (1982).
It also seems necessary for society to examine the direction research is taking, how scientific and technological advances are being used and their sometimes unexpected repercussions, and to exercise a certain degree of control over developments (Salomon, 1992). In particular, we should aim to use technology in such a way as to reduce the social marginalisation of certain population groups rather than worsening their situation (too often, technological progress widens the gap between those who possess or have access to them and those who do not).
For example biotechnology ought to be used to improve the nutritional status of all in the 21st century. This seems to be one of the main implications of the new technologies for the coming years, in agriculture as in other spheres, and an essential condition for a sustainable development model. ●

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