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NEW BIOTECHNOLOGIES FOR RURAL DEVELOPMENT

by

Pablo Bifani

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PREFACE

This study by Dr. Pablo Bifani is in a series on employment and income implications of new biotechnologies for Third World countries, which are prepared within the framework of the WEP Technology and Employment Programme.

The author assesses the potential impact of new biotechnology with special reference to agriculture and food production. Since the technology is still in an early stage of development, his analysis is often speculative. An effort has been made, however, to illustrate its potentials with reference to actual experiences of Third World countries.

After clarifying the definition of biotechnology and differences between new and traditional biotechnologies (Chapter I), Dr. Bifani explores obstacles to the growth of agriculture and food supplies, and the possible role of new biotechnology in reducing or overcoming such obstacles (Chapter II). Chapter III reviews some concrete cases of biotechnology applications for productivity increase, fertilisation, rapid micro-propagation of plant varieties, pest control, and production of microbial pesticides, while Chapter IV deals with cases of new biotechnology applications in food production and processing. Chapter V examines negative effects on the Third World countries that are likely to arise from the application of the new technology by developed countries in their effort to substitute raw materials imported from the developing countries.

The author believes that advanced and new biotechnologies can be applied immediately in several areas of agriculture and food production, and that experiences gained from the use of relatively simple and less capital-intensive biotechnologies like tissue culture is likely to facilitate the development and diffusion of more sophisticated technologies such as genetic engineering. In the short run, the employment impact of new biotechnology in agriculture and food production is likely to be more significant qualitatively than quantitatively giving rise to a demand for multi-disciplinary and other highly-qualified manpower. In the longer term, however, it can have significant quantitative impact on employment and occupational structure.

The use of new biotechnology by the industrialised countries, can have negative effects on the Third World economies. These countries therefore need to be watchful and ready to react appropriately. At the same time, the new technology itself may provide them with a solution to the problem e.g. by creating a new use of raw materials displaced from international markets.

New biotechnology is still at a very early stage of development and diffusion. Developing countries should be encouraged to get involved in the process. For this purpose, however, they will need integrated technological and development policies, and probably also new organisational structures and managerial practices.

GLOSSARY¹

AMINO ACID: Basic component of proteins. The chain linkage of amino acids in a particular sequence determines the character of the different proteins. The best known include: aspartic acid, glutamic acid, lysine, leucine, glycine, phenylalanine, proline, triptophan, tyrosine, methionine and asparagine.

ANTIBODY: Protein component of the immune system of mammals that is found in the blood and can react in the presence of one or more types of antigen.

ANTIGEN: Usually a protein or carbohydrate which, when introduced into the body of a human being, or of an animal, induces the production of an antibody that reacts specifically with it.

BACTERIA: Microscopic organisms of various shapes that constitute unicellular or acellular bodies, commonly agglutinated in colonies. They are enclosed within a cell wall or membrane and lack a differentiated nucleus. They may exist as free living organisms in soil, water or organic matter, or as parasites in the living bodies of plants and animals.

BIOCATALYST: Enzyme that activates or speeds up biological or industrial processes.

BIOCONVERSION: Chemical conversion by a biocatalyst.

BIODEGRADABLE: Descriptive of substances that are decomposed by the activity of micro-organisms.

BIOMASS: Any organic substance resulting from the photosynthetic conversion of solar energy.

BIOPOLYMER: Organic compound with a high molecular weight found in nature including cellulose and the principal components of wood, jute, cotton, etc.

BIOSYNTHESIS: Production of a chemical compound by synthesis or decomposition caused by living organisms.

CALLUS: Undifferentiated mass of plant cells that constitutes a first step in the regeneration of plants in the tissue culture technique.

CATALYST: Substance that increases the rate of a chemical reaction without being consumed during the process.

CELL LINE: Cells that have the ability to multiply themselves indefinitely in vitro.

CHROMOSOME: Unit of the genome made up of linear or circular molecules of DNA with or without the proteins associated therewith.

1. Source: Pablo Bifani: "Biotechnology: Overview and Developments in Latin America", in IDB: Economic and Social Progress in Latin America - 1988 Report, Washington D.C., 1988.

CLONE: Group of individuals obtained from a single individual by an asexual process that does not entail any exchange or combination of genetic material. Consequently, the individuals obtained from a clone are genetically identical.

CULTURE (CULTURE MEDIUM): System of nutrients required for the artificial cultivation of bacteria and other cells.

ENZYME: Complex protein produced by living cells that is capable of catalyzing specific biochemical reactions.

FERMENTATION: Enzymatic transformation of organic substrates, usually accompanied by the production of gas; physiological counterpart of oxidation that permits certain organisms to live and grow in the absence of air. It is used for the manufacture of such products as alcohols, acids, cheeses, etc.

GAMAGLOBULIN: Type of blood protein that plays a predominant role in the immune process.

GENOME: Chromosome complement of an organism or set of hereditary material (genes). It may be composed of one or more chromosomes, depending on the complexity of the organism.

GENOTYPE: Genetic characteristics of an individual or group.

GERM PLASM: Total variability of genetic material of a particular species.

GLYCINE: Simplest of the amino acids.

GROWTH HORMONE: Hormone produced by the anterior pituitary. Chemically, it is a peptic acid made up of fourteen amino acids. Its principal effect is the stimulation of the growth of the skeleton, but it also plays a role in the metabolism of fats, proteins and carbohydrates.

HORMONE: Product of living cells that circulates in the fluids of both animals and plants and which acts as a chemical messenger inhibiting or stimulating the activities of cells distant from the place in which it is produced.

HYBRIDIZATION: Joining of two complementary strands of RNA or DNA, which gives rise to a double-stranded molecule.

IN VITRO: Descriptive of a living culture in a free cellular system lacking cell membranes.

IN VIVO: Descriptive of a living culture within a cell or organism.

INTERFERON: Type of protein with a low molecular weight that is important in the immune function and is used because of its anti-viral action.

ISOMERASE: Enzyme that catalyses the transformation of a compound into its isomer.

LIGNOCELLULOSE: Complex biopolymer that includes the mass of woody plants.

LYMPHOCYTE: Type of cell found in the blood, the spleen, the lymph nodes, etc. of higher animals. A subclass of lymphocytes produces and secretes antibodies.

METABOLITE: Product of metabolism.

MICROBIOLOGY: Branch of biology that deals especially with the study of the microscopic forms of life.

MICRO-ORGANISM: Any organism that requires a microscope to be seen.

MOLECULAR GENETICS: Study of the nature and biochemistry of genetic material. It includes genetic engineering technologies.

MONOCLONAL ANTIBODY: Antibody produced from a single source or clone of cells that recognises only one type of antigen.

MUTATION: Any change in the sequence of chemical composition of the bases contained in DNA molecules. It alters genetic material.

MYCORRHIZA: Root fungus; an association of fungi with the roots of trees and other plants that increases the capacity of a plant to absorb nutrients from the soil.

NITROGEN, FIXATION OF: Conversion of atmospheric nitrogen into a biologically available form by nitrogen fixing organisms.

NUCLEIC ACIDS: Long-chain molecules that usually occur in combination with proteins. The two main types are ribonucleic acid (RNA) and deoxyribonucleic acid (DNA). Each nucleic acid chain is composed of sub-units (monomers) that contain a sugar, a phosphate group, and one of four possible bases. The specific sequences of these sub-units constitute the genetic information of the cell.

PATHOGENIC: Descriptive of an entity that causes disease.

PLASMID: Circular segment of DNA that is used as a vector for cloning DNA in the host cells of bacteria.

RADIOIMMUNOASSAY: Sensitive method of measuring traces of a hormone (or other biomolecule), based on the ability of a hormone to displace radioactive forms of the hormone from their combination with specific antibodies.

RECOMBINANT DNA: DNA formed by the conjugation of genes in a new combination.

SCALING-UP: Traditional stage in the transformation of a process from its experimental scale to an industrial scale.

SOMATOSTATIN: Growth hormone.

STEROID: Compound composed of a series of four carbon rings joined into a structured unit. Any substance of the group of the lipids that occurs naturally and is essential for life.

SUBSTRATE: Substance on which an effect is exerted, for example by an enzyme.

TISSUE CULTURE: Method for the in vitro growth and conservation of animal and plant cells, which is applied outside the organisms of which they form part.

VECTOR: Agent for the transmission of genetic information from one cell or organism to another. The vectors usually selected are plasmids, although viruses or other bacteria may be used.

CHAPTER I

BIOTECHNOLOGY: DEFINITIONS, CHARACTERISTICS AND BIASES

The development and application of biotechnology raise numerous fascinating, speculative and extremely important policy issues. In spite of recent discussions on the subject, biotechnology remains mainly in the fields of chemistry, biology or microbiology. And it enters the economic and policy-making areas in a very vague manner. The situation is even more unclear in relation to developing countries. Yet it is repeatedly argued that biotechnology will provide appropriate solutions to the socioeconomic problems of the Third World.

Several questions need to be examined separately but without losing their extremely relevant interdependence: e.g. what is biotechnology? In which economic sectors is it likely to produce major impact? What is the stage of development of biotechnology? Why and how is it so relevant for developing countries? What are the conditions that developing countries must fulfil to benefit from biotechnological development and application? What is the international setting in which these developments should be analysed? And what are the international dimensions that condition its development and application in developing countries? In addition, biotechnological development requires an approach different from the one traditionally used in the analysis of the economic, social and political implications of technological development, transfer and application.

No historical data exist for new biotechnologies. There are no statistics for capital investments, neither for employment created or eliminated. There are no data about capital requirements, levels of productivity, and so on and so forth. Economic decisions in the field of biotechnology involve the consideration of new techniques, new procedures, new forms of organisation and managerial practices and infrastructural requirements for which an adequate sampling of operating facilities does not yet exist.

In the absence of historical data, estimates of socioeconomic effects must be derived speculatively rather than objectively. Therefore estimations and value judgements would be questionable, and controversy is very likely to arise.

An examination of the socioeconomic implications of biotechnological development has additional implications. It implies a concern for technology in a dynamic perspective, and it forces us to look at potential feasible technologies rather than at the existing technology shelf. It is necessary to move from the traditional problem of the choice of technology out of a given set at a point of time, - which is a static problem - towards the analysis of the dynamic setting in which technological changes occur.

Some definitions of biotechnology

Several definitions of biotechnology have been provided in recent years by different institutions and experts. This proliferation of definitions is partially the consequence of multidisciplinary character of biotechnology which reflects the difficulties encountered in establishing its boundaries. However, it is also a reflection of the diversity of its scope. In a sense, one or another definition is adopted in accordance with particular interest regarding the purposes of biotechnology development and applications.

Frequently, biotechnology is defined as the industrial exploitation of biological systems or processes.¹ The Spinks report refers to it as the application of biological organisms, systems or processes to manufacturing and services industries.²

In 1981 the European Federation of Biotechnology adopted the following definition: "The integrated use of biochemistry, microbiology and engineering sciences in order to achieve technological (industrial) application of the capabilities of micro-organisms, cultured tissue cells and parts thereof."³

The FAST programme of the European Community provided a slightly different definition: "The industrial processing of materials by micro-organisms, and other biological agents to provide desirable goods and services."⁴ In its turn, the OECD defined it as "the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services."⁵ This definition has been adopted in some European countries, Spain for example.⁶

In 1981, the Office of Technology Assessment (OTA) of the Congress of the United States in its report "Impacts of applied genetics", defined biotechnology as the collection of industrial processes that involve the use of biological systems, the use of living organisms or their components in industrial processes.⁷ However, later on, the same OTA provided the following wider definition: "any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses."⁸

The Italian Government has adopted a wider definition which refers to the utilisation of biological systems for obtaining goods and services including activities of agriculture and both traditional activities as well as advanced development in industry and pharmaceuticals.⁹ Other approaches avoid defining biotechnology and prefer to refer to it in terms of a system or arrangement of different disciplines and activities. Thus, for instance, Prentis stated that "biotechnology encompasses many activities, which have in common the fact that they all harness the fundamental abilities of living organisms".¹⁰

The above definitions have one common aspect: they refer to the use of micro-organisms and biological agents. However, each of them reflects different purposes, or interests and strategies. Most of them emphasise explicitly the industrial character or relevance of biotechnology. The definition by the European Federation of Biotechnology stresses the interdisciplinary character of technological development, but ignores the economic and productive dimensions, while others indicate an economic purpose. Yet none of them gives an accurate and systematic picture of different techniques on the basis of any economic criteria.

Traditional vs. new biotechnology

Biotechnology is not a new technology. It has been used in the manufacture of food and beverages for thousands of years. This is why it is useful to make a distinction between traditional and new biotechnology.

But is it possible to establish a clear division between the traditional and the new biotechnologies? To answer this question, one needs to go back into history.

The story of biotechnology can be divided into at least four periods. The pre-Pasteur era, which is confounded with the beginning of mankind and the

empirical practice of selection in animal and plant breeders and fermentation for food preservation. This era lasted until the second half of the nineteenth century and can be characterised by the artisanal application of empirical understanding resulting from experience alone. The selection and breeding of plants was a slow trial-and-error process performed without knowledge of the laws of inheritance. In its turn fermentation was used for millenia without understanding that it was a biological phenomena produced by the activity of living organisms. Serendipity occasionally contributed to impel economic biotechnology application as in the case of penicillin. But it was practical understanding without theory or scientific base. These techniques were transmitted from one generation to the following one. It was technology without science.

The second biotechnology era initiated with Pasteur. It identified micro-organisms as the cause of fermentation which was followed by Buchner's discovery of the capacity of enzymes extracted from yeast to convert sugar into alcohol. This development gave impulse to fermentation technique in the food industry through the production, among other products, of baker's yeast and citric and lactic acids, and in chemical industry, for the production of acetone, butanol and glycerol through the use of bacteria.

The third era was characterised by important technological developments which reduced the impetus of biotechnology development in certain areas while giving a new big push in other areas. So the expansion of the petrochemical industry displaced the chemical processes based on fermentation. But at the same time Fleming's discovery of penicillin in 1928 permitted the large-scale production of antibiotics at the beginning of the 1940s while the 1930s saw the beginning of the spectacular increases in yield of corn per hectare in the corn belt of the United States, which indeed paved the way for the Green Revolution.

The last era started with the discovery by Crick and Watson of the double helix structure of DNA in 1953, which was followed by the process for enzyme immobilisation, the first experiments on genetic engineering, in 1973 by Cohen and Boyer, and the discovery of the hibridoma technique for the making of monoclonal antibodies in the first half of the 1970s by Milstein and Koehler. These are the basic developments that boosted the new biotechnology in the early 1980s and that are at present in full expansion in different areas: agriculture, food processing and conservation, health care and medicine, industry and mining.

The new biotechnologies can be classified into the following four groups:

- a) techniques for cell and tissue culture which are likely to produce a large impact in agriculture;
- b) technological development associated with the fermentation process particularly those in the chemical sector, which includes the enzyme immobilisation technique. This group of techniques is already producing major impacts in several industrial branches, in particular, the production of enzymes, (mainly protease, glucoamylase, alpha-amylase and glucose-isomerase; aliphatic organic compounds like ethanol, n-butanol, acetone and acetic, citric and lactic acids) and the production of aminoacids, in particular lysine and glutamic acid;
- c) techniques that apply microbiology for the screening, selection and cultivation of cells and micro-organisms; and finally,
- d) techniques for the manipulation, modification and transfer of genetic material. This is basically genetic engineering.

One interesting aspect of the new biotechnology is that the four groups outlined above are mutually supporting. However, there is one fundamental difference between the first three groups and the fourth. The first three groups as well as all traditional biotechnologies were based on the empirical or scientific (after Pasteur) understanding of the characteristics and behaviour of micro-organisms and the deliberate use of the characteristics of each particular organism for the achievement of economic objectives. The enormous potentialities of the last group derive from the capacity to manipulate the structural and functional characteristics of organisms and the application of this capacity to overcome their natural limits in performing specific tasks that have economic and social interest.

A second fundamental aspect of new biotechnology is that it is science intensive. In the pre-Pasteur period biotechnology involved the application of practical experiences transmitted from one generation to another. With Pasteur the scientific knowledge about the characteristics of micro-organisms oriented their utilisation, but the technological application remained basically artisanal with the exception of a few industrial chemicals like acetone, butanol and glycerol and esteron (1944), the large-scale production of penicillin, which initiated the technological research within the large corporations. In all these cases, technological innovation arose mainly from the productive sector. The new biotechnologies, on the other contrary, are science-based. All the major innovations and discoveries of new biotechnologies have occurred in the research centres and universities. This aspect, one of the most relevant of new biotechnologies, has been the subject of debate. So has been the initiation of a new technological pattern characterised by the increasing association between large corporations and universities either directly or through intermediate firms.

For developing countries this characteristic of the new biotechnologies is extremely challenging for two main reasons. Firstly, the linkages between the productive sectors and the research centres and universities are particularly weak if not non-existent. Secondly, research centres and universities in many developing countries have the scientific capacity to participate actively in the development of new biotechnologies and their application to local problems. But this requires a drastic change in the scientific and technological policies of these countries for the creation of linkages between productive activities and research and academic centres where those links do not exist, or for their strengthening if they already exist.¹¹

Finally, a wider definition of biotechnology and a clear understanding of the interrelationships between traditional and new biotechnology illustrates the fact that biotechnology is rooted in vernacular technologies which can be a favourable element for the rapid and smooth diffusion of new biotechnologies and for the merging of new and traditional technologies.

Nature and characteristics of new biotechnologies

Different concepts have been used by economists to differentiate technological innovations depending on the magnitude of change that they generate. So a distinction is made between production-specific technologies which produce effects within the sector or even the branch of the economic activity where the innovation is applied; and generic technologies which create effects that are pervasive in other areas of the economic system. Biotechnology is a generic type of technology. In fact, it is a complete set or system of interrelated innovations which can be applied in every area of the economic activity and each one of these applications generates effects that go beyond the limits of the sector. For this reason, people refer to biotechnology as a new technological revolution or a new paradigm similar to the one generated by the advent of microelectronics.

However, it seems important to distinguish clearly between the characteristics of microelectronic revolution and biotechnological revolution. A comparative analysis of both goes beyond the scope of this paper. Yet a few elements can be mentioned here: in microelectronics the main innovation refers to products which have a rapid diffusion into the market. Biotechnologies, on the other hand, emphasise process innovation, while new biotechnological products are entering slowly into the market. In microelectronics there is a rapid return on investment while in biotechnology the return on investment is relatively slow. Finally, microelectronics has been the result of industry-oriented research while biotechnology is the result of scientific research closely linked with research centres and universities. Microelectronics illustrates the demand-pull hypothesis while biotechnology represents a case of supply-push hypothesis.

From a different perspective a distinction is made between incremental and radical innovations. While the former refers only to the improvement of existing processes and products, radical innovation refers to those that are discontinuous events associated with the long cycle of the economy. Finally, there are the technological revolutions which have pervasive effects throughout the socioeconomic system and include process as well as product innovations. In this sense, a technological revolution can be considered a change of the existing paradigm.

Freeman¹² has identified five fundamental characteristics of a technological revolution, viz.

- a drastic reduction in cost of many products and services;
- a dramatic improvement in the technical characteristics of processes and products;
- social and political acceptability in the sense that innovation is socially accepted but it involves modification in the legislative, educational and regulatory patterns of society and changes in management and labour attitudes;
- environmental acceptability;
- pervasive effects through the economic system.

These five characteristics or conditions are likely to be met by future biotechnological developments.

All the productive activities from the primary ones like mining and agriculture to manufacturing and services are likely to be radically affected by biotechnology developments which are in fact blurring the traditional boundaries between productive sectors and between these and services (e.g. health and environmental services).

Biotechnology overcomes the traditional sectoral classification systems of macroeconomic accounting. This implies greater flexibility of the economic activities which will be reflected in scale operation and in a new approach towards the integrated management of resources in search for more optimal technological and economic solutions. In this respect it is necessary to think not only in terms of products or processes, but rather in terms of systems in which both products and processes and their complementarity are relevant. Among the questions that arise are: whether this shift is towards a more labour-intensive or a more labour-saving direction, and what type of resource endowments would facilitate the adoption of a new technological pattern.

Biotechnology depends on the interrelated efforts of different scientific disciplines. Technologies should therefore be operated by multidisciplinary

teams supported by a wide range of information and services provided by different disciplines. It is an information-intensive technology. Its development, application and optimal use can be accelerated by the growing capacity to gather, store, retrieve, manage and interpret scientific, technological and economic information.

On the other hand, biotechnology is characterised by the great generality of its methods. Hence their applicability to different economic activities with different economic relevance. For example, the fermentation process is based on the same principle whether it is for the bulk production of ethanol or for the production of antibiotics. Thus different economic sectors, like energy and pharmaceuticals can use the same methods for completely different purposes. The implications of this aspect are very important, and their magnitude is a matter of speculation. For example, the fact that the same methods are applied in different sectors implies a greater flexibility, for it would allow mobility of factors of production of completely different characters from one sector to another. In the case of employment, for example, it means that a new skill profile should evolve both in quantitative and qualitative terms.

The flexibility and potentiality of the productive system are further enhanced by the fact that biotechnology is based on the utilisation of a wide range of biological catalysts, and in particular micro-organisms, such as enzymes, bacteria, algae, fungi, yeasts, animal and plant cells, or any isolated components of living matter. Energy production process that uses carbon-based material is being affected by biotechnology. For this reason, one of the advantages of biotechnology is assumed to be an adequate utilisation of biomass. In this perspective the exploitation of renewable resources should not be limited to the possibility of energy production, but should rather embrace a wide spectrum of products, from those of relatively low aggregate value to products of relatively high aggregate value. However, it should be clear that biotechnology is not restricted to the utilisation and processing of renewable resources. Traditional non-renewable resources as well as inorganic material can be used as raw materials for biotechnological process, or can be transformed by the use of living organisms. Hence hydrocarbons, traditionally a non-renewable resource, are being used for the production of a single cell protein (SCP) that replaces soyabean in cattle feeding. On the other hand, micro-organism can be used for metal leaching from minerals, and metal concentration, or for oil recovery.

Therefore, biotechnology is not only adding new products and raw materials, but it is also offering new possibilities for the production of traditional goods and services, thus enabling increasing flexibility in the economic system.

There is no doubt that biotechnology has the potentialities to create a technological revolution in the Schumpeterian sense. However, it seems that its diffusion is still facing structural barriers in the socioeconomic and institutional system and has difficulties to overcome the inertia of the present technological system. In this context, it can be accepted, as Perez¹³ stated, that biotechnology is still a "technological paradigm" meaning a new combination of innovations which differ radically from the existing ones and confront problems of institutional changes, and social and market acceptability.¹⁴ Biotechnology will create a real new paradigm only when those socioeconomic and institutional barriers will be overcome. This is what Perez called "a new techno-economic paradigm."

It is clear that technology being a system of inter-related innovations, not all of them are progressing at the same pace. Market situations, social

acceptability, return on investment, managerial aspects as well as other factors, favour the diffusion of some of them instead of others. So it seems that for the time being in developed countries biotechnologies associated with high-value products are progressing more quickly while those in other areas like agriculture and mining lag behind.

However, in developing countries agriculture and food production are the strategic sectors in terms of employment and income generation and distribution. What potentialities can biotechnology offer and how can these potentialities materialise? What are the conditions to fulfil and the barriers to overcome? Some answers to these questions give us the reference point for this paper. Moreover, it is also likely that biotechnological development will have adverse effects on developing countries in so far as it results in the reduction of international demand for traditional commodities or displaces them by new products resulting from biotechnology diffusion. In this case, employment, income generation and distribution in developing countries will be adversely affected.

Industrial bias in biotechnology applications

Most of the work done so far on new biotechnology is concerned with the industrial sector with little attention to the agricultural sector. This reflects the particular European problem and that of industrialised countries in general. It also indicates a traditional bias in discussion on technological innovation which is considered relevant mainly to the industrial sector. This is an important point since on the one hand it reinforces the more or less tacit assumption that technology innovation is generated in the North, and on the other, it defines the role of the periphery in the future development of new technology.

According to the OECD definition (cited above), medical technology and medical treatment, agriculture and crop and animal breeding, are not regarded as biotechnology. Indeed, this is a very controversial assertion. The OECD definition clearly emphasises that goods are considered as the products of industries concerned with food, beverages, pharmaceuticals, biochemicals, and the winning of metals, while services include industrial and domestic waste management and water purification. However the OECD added that some aspects of agriculture, crop breeding etc., must be considered, because plants provide the raw materials for most biotechnological processes. In addition, it recognises that through the production of microbial pesticides and modern genetic manipulation, in vitro propagation of animal and crop varieties and improved nitrogen fixing capacity, biotechnology will have a profound impact upon agriculture in the future.

An additional explanation of the industrial bias of the discussion on biotechnology is found in the existing institutional mechanisms for the protection of industrial property, particularly the patent system. This has been normally concentrated on inanimate matters, artifacts, industrial processes, equipment and industrial products. Living organisms (micro-organisms), processes based on the manipulation of micro-organisms, plant breeding techniques and products, health care methods for human beings and animals, therapeutic techniques and diagnostic methods as well as biological processes, have been traditionally excluded from the patenting systems of many developed countries. Finally, it is also a reflection of the bias that tends to associate technological progress with whatever happens in the industrial sector.

While it is true that technological development is at the origin of industrial expansion, it should not be neglected that the technological

phenomena are not sector-specific, that they embrace all socioeconomic activities, and that they play a crucial role in medical and health care development as well as in the constant increase of agricultural production all over the world.

In industrialised countries technological development has played, inter alia, two different roles in agriculture and industry. In agriculture, both radical and incremental innovations were oriented towards raising agricultural productivity and production of raw materials, food and feed. In industry, raising productivity and production have also been an objective of high priority. However, technological innovation, and in particular, basic or radical innovation in Schumpeterian sense, play an important role in shifting from the declining industrial branches to the new ones which slowly assume the role of dynamic forces behind the economic process. This is illustrated by the historical shifts from the steel and coal industry to metallurgy and manufacture of durable equipment and finally, to the chemical industry.

Today, developed countries are confronted with an agricultural crisis characterised by growing surpluses of food and commodities, which affect the prices and increase the burden for governments and consumers alike. In this context, any technological innovation that tends to increase agricultural production is likely to contribute further to agricultural crisis. So the development of biotechnologies has spurred debate about their role in increasing output. Major productivity gains are expected in livestock, plant agriculture and processing as new developments in in-vitro culture and gene-splicing sciences move ahead. For example, the advent of bovine somatotropin (BST) or bovine growth hormone (BGH) means that the existing over-production of milk in developed countries will increase again at little if any cost to the farmers. But this development comes at a moment when the Government of the United States is killing one million dairy cows in an effort to reduce milk surpluses that have cost more than US\$1,000 million annually. The European Common Market has huge surpluses of butter (1.3 million tonnes), milk (900 thousand tonnes), beef (630 thousand tonnes) and cereals (13 million tonnes) which are costing more than US\$10,000 million annually without considering the increasing subsidies provided out of national budgets. (For example, the French Government subsidies to support farmers will reach 600 million francs in 1987). In addition the Community will pay EC10 (EC European currency = US\$1.082) for every 100 kg of milk not produced and EC25 for each head of cattle reduced. Also the countries of the Community are selling beef at less than one-third of the European internal market price to North African countries in order to get rid of their surpluses, thus displacing traditional supplies from developing countries like Uruguay to the Arab market. The Chairman of the House of Agriculture Sub-Committee of the United States put his concern clearly when he said: "Nobody has demanded that BST be developed. Consumer demand is not there. Dairy industry demand is not there. My concern is that we are going to let the big get bigger." On the other hand, the Environmental Policy Institute stated that "We simply are not prepared for the productivity burst that is coming in agriculture ... The BST technology really has the potential to destabilise the milk industry, commodity markets and our agricultural policy."¹⁵

The main purpose of the European biotechnological programme is to avoid a crisis in the chemical and petrochemical sectors. It is motivated by the fear that a crisis similar to the one suffered by the steel industry will be reproduced with larger and more profound effects, and this will occur mainly for two reasons: the chemical sector has complex ramifications over the totality of the economy: agriculture, medicine and health care, building, services, food production, energy, the environmental effects, etc. The apparently better position of Japan and the United States, in respect of

biotechnology raises a European concern and fear of being excluded from a potential market. In this context, biotechnology is considered as the element that can contribute to solve the actual problems of the sector such as increasing idle capacity, growing costs, dependency on foreign sources of raw materials (oil), environmental constraints, lack of dynamism as job generator, associated with a stagnant demand and a market saturation. In such critical situations the chemical sector has revealed a rather rigid structure and inability to adapt. At this turning point, the chemical industry is trying to move from the "chemistry of products" towards the "chemistry of functions"¹⁶ which would allow the integration of this sector into others e.g. energy. In this strategy, biotechnology can play a relevant role by creating new products, and new sources of raw materials, and by reducing the vulnerability of the chemical industry, conferring to it a greater flexibility, and reducing its capital-intensive character, by the use of methods less intensive in the use of energy (in particular, hydrocarbons), favouring the relocation of the industry and augmenting the value of natural resources and of activities either based on the production of bulk products of relatively low value added (ethanol) or products of very high value added (pharmaceuticals). Finally, biotechnological process can contribute to the reduction of a negative environmental impact of the industry, either directly or indirectly, by the use of less or non-pollutant techniques, or by the application of biotechnologies for waste processing.

The fact that the industrial potentialities of biotechnology are emphasised, while the agricultural aspects are excluded or considered only marginally, is but a confirmation of the hypothesis that technological development responds mainly to the specific problem of those regions where it originates.

In this perspective, the role of developing countries will be the same as traditionally performed, that is, as receivers of equipment, know-how, and new products or traditional products obtained by new processes. These will allow them to supply the centre with raw materials for the new industry which, in its turn, will help reduce European dependence on some commodities such as tropical products, fats and oils, protein (soyabean) and so on.

However, in developing countries the situation is different. It is not only a problem of industrial adjustment but rather a complete development strategy and policy which are being questioned. Biotechnology discussion arises at a moment in which the traditional agricultural policy and the contribution of agriculture to economic growth and development are revised with skepticism in search for a new approach. In this debate, the role played by technological diffusion in the agricultural sectors of developing countries constitutes one of the major issues. Biotechnology potentialities for agricultural development in the Third World countries must be carefully assessed. For this purpose a wider definition of biotechnology is adopted here. It includes all agricultural activities and techniques for their transformation and preservation.

CHAPTER II

AGRO-ECOLOGICAL DIMENSIONS, PRODUCTIVITY AND TECHNOLOGY

Technological innovations in agriculture have been largely the extension of innovations in the industrial sector. Thus agricultural mechanisation was in fact an adaptation to agriculture of the developments occurring in the energy and automobile industries. Agro-chemicals' innovations were the result of innovations in the petrochemical sectors which also motivated the R&D on biological innovations as a form to expand and to capture new markets for the chemical sectors. These two types of innovations in the mechanical and the biochemical spheres constituted a technological package that was mainly labour saving.

Three consequences of these innovations are: first, the increasing dependence of agricultural activities on the natural and growing supply of industrial inputs. Secondly, a certain release from natural constraints occurs without altering the basic process of agriculture which is determined mainly by natural phenomena. Thirdly, employment per unit of land cultivated continues to diminish.

The natural character of agriculture defines a set of constraints that cannot be removed by technological progress. Technological innovation has not been oriented to the modification of the natural process of production, but rather to the improvement of the efficiency of the associated human tasks in agriculture, and to the maximisation of economic yields of the natural process by the application of the industrial inputs that stimulate specific natural reactions.

Exploration of the implications of biotechnology for future agricultural development requires, first, the identification of the above-mentioned constraints, secondly, revision of the technological innovations applied to agriculture in order to understand why biotechnology represents a new phase, or paradigm in agricultural technological progress.

The agricultural constraints derive from the following main issues:

- biological harvesting and conversion of solar energy on which agriculture is based;
- soil that is indeed a complete system of living organisms and inorganic materials in a dynamic interaction;
- immobility or spatially-fixed characteristics of land. This aspect has two dimensions: the problem of immobility in itself, and the very specific geographical location which implies different soil characteristics, climate and ecological characteristics, and their inter-relationship which determines how the productive functions are performed;
- seasonality character of nature; and
- time dimension.

The above natural constraints define the type of crops to be grown, the requirements of skills and quantity of labour requirements, the suitability of any given technology, agricultural practices, productivity, economic organisation, and so on. A brief discussion of these constraints is therefore necessary to understand how new biotechnology is likely to affect agricultural and food production, and why biotechnology implies an historical turning point for agricultural technological process. Besides, this knowledge is useful for

the understanding of productivity differences between different regions as well as problems faced by the transfer of technology to agriculture.

The geographical location associated with ecological conditions and soil characteristics constitutes the agro-ecological dimension which determines natural productivity, regional specialisation, technological requirements and levels of employment. These issues are the concern of this chapter.

1. Agro-ecological Dimensions

Agriculture can be considered as a solar energy harvester and processing system which is determined by natural conditions (a combination of ecological and climatic conditions: soil characteristics, topography, diversity and features of the biotic and abiotic elements, level and seasonal distribution of sunlight, temperature and precipitations) and by socioeconomic, political and cultural phenomena.

The dynamic interrelations among the above factors define the potentialities and constraints of each particular geographical area. During millenia mankind has developed farming practices that searched the optimisation of the natural conditions. Empirical knowledge led to artisanal capabilities for the domestication of several species, which provided the basic commodities for the satisfaction of human needs. Such a domestication was adapted to the climatic and ecological conditions of each particular area. Thus, regions characterised by marked seasonality with regular precipitations during the year, and low evaporation, were found suitable for wheat cultivation which has a relatively low demand for water, and moderate requirement in terms of soil moisture and suitability to grow well during the cool weather of spring and fall. In the semi-arid regions where the limited rain is not regularly distributed during the year, falling mostly in the warm season with high evaporation, drought-resistant species were needed. Sorghum and millet have therefore been the traditional crops of these areas. The geographical spaces with fertile, well-drained soils, and with moisture well distributed during the warm seasons, are favourable to the production of crops like corn and soyabeans.

In tropical areas where the growing season is long, the most appropriate crops are the ever-bearing plants, and year-round sequences of food crops like roots and tuber crops (potato, cassava, yams) or peas, beans, nuts, and oil seeds.

The situation is far from simple because growing seasons and factors limiting agriculture depend on a very complex network of dynamic phenomena which also vary according to the geographical location. While in temperate areas the crop-growing season is determined by temperatures and, to a lesser degree, by the occurrence of frost at the beginning and/or at the end of it, in tropical regions the critical elements are rainfall and water availability. Seasons are not the same as in temperate areas. In tropical climate, a distinction is made between dry and wet seasons. With few exceptions like high altitude, temperatures in tropical areas are more or less adequate for crop growth throughout the year.

In addition, it is not only temperature or/and water availability or rainfall but interaction among them and with soil characteristics that is relevant. In temperate regions, during the winter, the rainfall largely exceeds evaporation and the soil has the capacity to retain water, creating a reserve that will be used in the summer, or during the crop-growing period, when evaporation exceeds rainfall. Temperate soils suffer little leaching beyond the crop root zone during the growing season, while in tropical areas -

particularly in some very specific ecosystems like tropical savanna - the little water retained by soil in the root zone is exhausted by the end of the growing season and therefore crops are very vulnerable to the variability of the arrival of the next rainfall. A relatively large rainy season can seriously affect agriculture, a situation that is aggravated by a more intensive and continuous leaching of water during the wet season. Furthermore, the intensity of tropical raining results in less infiltration of water into the soil, hence relatively large surfaces run off, a phenomenon that, when associated with overgrazing and intensive deforestation, can result in erosion and flooding.

However, the moisture depends not only on rainfall, but also on evapo-transpiration which, when it increases, rainfall decreases. When evapo-transpiration is larger than rainfall, then the agricultural potentiality of the region depends on the length of the raining period and the distribution of rain during the period. Thus it is possible that, from a purely rainfall point of view, an apparently good area for maize is not as good if evapo-transpiration exceeds rainfall. For example, in the traditional shifting cultivation system practised in Ghana, water availability is important as a limiting factor. In the south of the country, the first annual crop after clearing is maize which is planted between March and April and harvested in July/August. By this time the farmer has two options: either to go to a second crop which demands less moisture or to take the chance of the extra benefits of a possible second minor rainy season. In the first case, most probably the farmers will plant cassava, while in the second, they will try an early maturing variety of maize which is a more interesting crop than cassava from the economic point of view, and which is easier to conserve during the dry season. If an inter-cropping system is used, maize is harvested in August while cassava continues to grow on the ground.

At lower latitudes, rainfall increases and therefore permanent and semi-permanent crops, like bananas or cocoa in the case of a cash crop, are preferred. Moving to the North-east of the country, rainfall decreases and the dry season lasts an average of seven months. Therefore, moisture is scarce making the area unsuitable for maize. In this case, the main crop is millet and the second crop is groundnut or guinea corn.

In the areas closer to the Equator it is frequent to have bi-modal rainfall pattern, with one long rainy season and a second short rainy season. When this situation occurs, (as in some parts of Kenya), maize is planted at the beginning of the long rainy season and early maturing varieties of corn or cowpeas are planted at the beginning of the shorter rainy season.

Temperature is a complex variable with quantitative and qualitative dimensions. It is generally believed that developing countries and tropical regions in particular, are warmer than temperate areas and since higher temperatures are favourable to growth, it is assumed that the potentialities of these countries are larger. Yet it is not necessarily so. The average annual temperatures hide the variability during the year and between day and night. Furthermore, it is important to distinguish between soil temperature and air temperature.

Developing countries are largely concentrated between the tropics of Cancer and Capricorn, which roughly defines the tropical and semi-tropical areas. In this region, there are areas of periodic low-soil temperatures which transform them either in desert or frost-prone areas. Among these areas can be mentioned the Northern part of the Sahelian belt, some parts in northern and Central India, the arid and semi-arid areas of Australia, the southern area of Bolivia and Peru, north of Chile and Paraguay, large parts of

Angola and Namibia, southern China, Brazilian North-east and the frost-prone areas of southern Brazil. Soil temperature alone is not the determining factor. It must be associated with the seasonal soil freezing, the occurrence, or not, of seasonal leaves' fall in moist or dry soil, etc.

Air temperature is also important because it affects the photosynthetic capacity of the plant. In areas where air temperature is relatively high, plants spend a large part of their energy into respiration during day and night, a phenomenon that does not occur in temperate areas, and can result in a relatively lower efficiency of the tropical regions.

High temperatures of the tropics and the larger growing season are associated with a great diversity of plants, thus favouring the growth not only of crops but also of a large variety of weeds. Therefore, in tropical areas weeds are a bigger constraint than in temperate areas. Besides, this greater diversity of plants constitutes an adequate habitat for pests and diseases, which are also more numerous and diversified in the tropical areas than in the temperate areas. The favourable environment created by higher temperatures and more diversified habitats of tropical regions results in greater constraints due to a more numerous variety of pest and diseases than those in temperate areas.

Finally, it is important to note that soil is a complete system of organic and inorganic elements which determine their fertility. Traditionally, it has been argued that large areas of tropical regions are often deficient in nitrogen and phosphate. This situation is also affected by the slope of land which can increase or decrease the run-off and therefore, the loss of nutrients, the depth of top soil, the soil density or compaction and the quality of soil, which determine its capacity to retain moisture. For example, clay soils retain more moisture than sandy soils. All of these factors interact with the kind of vegetation that covers the soil. Soil depth affects penetration of the roots and their elongation, and can reduce or enhance the emergence of seedlings. The effects of soil characteristics vary depending on the crops; thus maize and cotton are more affected by this variable than millet, for example.

In tropical and sub-tropical areas, particularly semi-arid regions, the soil characteristics are affected by the intensity of rainfalls. When soil has lower water storage capacity the surface may suffer from crusting which reduces the emergence of seedling, while at the same time, raising run-off and erosion and reducing the needed aeration around the roots.

The natural conditions that change systematically with latitudes and which depend on the above-mentioned factors, result in greater or less crop diversification. For example, only few crops occupy the cultivated area in the northern parts of West African countries where soil characteristics, rainfall and temperature offer a narrow range of possibilities. Yet, ten main crops are common in the regions of South West Africa, which is obviously related to the length of the rainy season. So millet and sorghum occupy more than 80 per cent of the total cultivated area in the very dry regions in the north of West African countries while they are scarcely cultivated in the more humid regions of the south, where a larger number of crops are cultivated. Each one of the factors mentioned: water availability, temperature, soil characteristics, determine specific farming systems establishing a relatively wide range of possibilities.

This range of possibilities, originally determined by the interaction of physical, chemical and biological conditions is further altered by socioeconomic activities, institutions, and structures which can, either

narrow the natural range of alternatives (for example, by accelerating erosion and desertification) or can extend this range of possibilities through scientific and technological development. Scientific understanding and technological development permit the domestication of new plants, their adaptation to different environments and the creation of conditions in such a way that natural constraints can be overcome.

From a different perspective, it is possible to say that the agro-ecological dimensions noted above are synthesised in the equation:

$$\text{GENOTYPE} + \text{ENVIRONMENT} \rightarrow \text{PHENOTYPE}$$

These agro-ecological conditions are modified by socioeconomic dimensions and scientific and technological applications, either applied on the genotype, on the environment or on both components. Therefore, farming systems can be defined in terms of agro-ecological dimensions (temperature, moisture regimes and soil characteristics), types of crops and socioeconomic dimensions (which include farm size, degree of self-produced or purchased inputs, labour skills and profile, institutional organisation and scientific/technological applications).

Employment implications

The above natural character of agriculture has important implications for employment and technology transfer. Each agro-ecological area determines a particular farming system with its own employment and technology implications. Furthermore, this implies existence of differences between agriculture and industry. First, industrial activities can be operated throughout the year while working days in agriculture are determined by the natural process of crop sowing, growing and harvesting. The average number of working days in the crop production of developing countries is estimated at less than 130 days, a very low figure (without considering livestock or other complementary operations). This means a large idle period for the labour force. Besides, while working periods in industry can be initiated any time during the year, regardless of weather or seasons, in agriculture the task is to be accomplished strictly during the time determined by the natural process and even more, production in agriculture cannot be arranged in series. In other words, while the manufacturing process can be disaggregated and arranged in sequence in order to maximise productivity, this is not possible in agriculture. Each task has to wait for its appropriate time. These factors impose serious constraints on employment creation: it is not possible to anticipate or to postpone tasks, thus labour should be available and ready at the right moment.

There are additional considerations. The vagaries of weather can result in serious employment distortions. The FAO reported that growth in labour productivity in Africa declined significantly during the early 1980s, compared to the 1971-80 period: it became even negative mainly because of widespread drought.¹⁷ Not only productivity was affected but also the level of employment as such. However, data on this subject are not available.

Furthermore, while mechanisation is favoured by farming systems based on extensive area cultivated with a single crop, and in particular, topographic land characteristics, this does not happen in some tropical or semi-tropical countries, particularly in the humid tropics where multiple-cropping systems are practised. Moreover, the situation also differs depending on whether sequential cropping or intercropping (implying intensification in time and space) is practised. The situation is even more unfavourable to mechanisation in the case of mixed farming, particularly when trees are involved.

The above factors explain, at least partially, why the measurement of employment in agriculture has faced so many difficulties. These arise from the definitions and methods of calculation adopted, which generally appear biased by the manufacturing employment patterns, as well as by the particular characteristics and diversity of agriculture, the crop cultivated, the seasonal factors and the vagaries of climate. Further complications arise because agricultural activities in developing countries do not fall within the common definition of work used in manufacturing and urban activities. The sheer lack of data is serious for many of the tasks performed, particularly by rural women. Even if women were recorded as wage labour in manufacture or urban activities, too frequently they are not recorded for agricultural activities performed.

In developing countries, the agricultural labour force has been increasing at a rate between 1.2 and 1.3 per cent per year. However, its share in the global workforce has been declining. In 1985, it was estimated to be 58 per cent of the total labour force against 67 per cent in 1970. This declining trend can be associated with the type of technology introduced and with the increasing relevance of intensification rather than the expansion of arable land. This fact has been particularly important since 1950. It has been calculated that during the last 20 years, about more than two-thirds of increase in production is explained by increases in average yields and cropping intensity. From the employment viewpoint, the importance of this trend can be appreciated by the fact that increases in output resulting from expansion of agricultural land call for one-to-one increase in labour, whereas the relation in the case of increases due to land intensification is between 0.1 and 0.5 depending on the technology, the crop and so on.

During the past few decades, mechanisation was promoted and accelerated by agricultural policies which encouraged it through subsidies, preferential import treatment, easy and favourable credit, services and so on. In some cases, as in Latin America, the extremely unequal distribution of land also favoured mechanisation. Obviously this policy accelerated the labour-displacing process that, to some extent, was inherent to this type of technology. However, the different agricultural farming system influenced the process that was accelerated more in Latin America than in other regions. (In 1982-84, tractors contributed 22 per cent to the total power in Latin American agriculture, whereas it represented only 14 per cent in the near East and north Africa, 4 per cent in Asia and barely one per cent in Africa south of the Sahara).

Another agro-ecological aspect with implications for technology and employment refers to weed control. Weed is a serious problem in tropical and sub-tropical areas. Weeding is a very labour-intensive task. The strategy adopted in many countries is to increase the use of herbicides. The major factor responsible for increase in agricultural production are fertilisers; their consumption in developing countries has been over 10 per cent per year. During the period 1961-1985, however, due to economic constraints in developing countries, it was reduced to approximately 5 per cent. In theory, fertiliser is land-saving and not labour-saving; moreover, since it also stimulates the growth of weeds, it should in fact result in an increase in employment. However, in some cases, this effect has been neutralised by the fact that fertiliser is largely applied in cash crops and in a "package" together with other inputs that displace labour.

It should be noted that since technology has originated mainly in temperate areas, based on large-scale exploitation of farms with scarce labour supply, it responds to these factor endowments. When transferred to developing countries, the technology has frequently been adjusted to some of

the local requirements, through adaptive research and innovation. However, in the great majority of cases, this adaptive effort has been conditioned by the prevailing economic objectives, strategies and policies. In general, these policies have focused on the most obvious and rapid method of increasing production. So exportable crops and large-scale operations have been favoured; to the neglect of rural employment and income generation. Therefore, although fertiliser use is most likely to have positive effects on employment, these effects are frequently counteracted by the emphasis on large-scale cultivation that favours mechanisation and labour displacement and the increasing use of herbicides which is also a labour-saving technique.

2. Biological and economic productivity

The agro-ecological dimensions of agriculture define a productive process which, to some extent, is independent of socioeconomic activities. The efficiency of this natural process can be considered as the natural productivity of the system which is known as "biological productivity".

Photosynthesis is the key process of life and the base of the agricultural activity. The harvesting of solar radiant energy and its conversion into chemical energy is a process unique to green plants and certain bacteria by which carbon dioxide is fixed into an organic compound. All the compounds that compose the organic world are derived, directly or indirectly, from carbohydrate. By the oxidation of organic compounds the stored energy is released and utilised by organisms to drive essential metabolic processes: through photosynthesis biomass is produced. Thus, the efficiency of photosynthesis as far as biomass production is concerned, is defined as the percentage of the total solar radiation, falling over a given area in a given time, which is converted into harvestable organic matter. The biological productivity is, therefore, defined in terms of the amount of harvestable organic dry matter produced per unit of land area per year expressed in terms of weight or energy content of material produced.

Species have different photosynthetic efficiency. Corn, sugarcane and sunflower are among the most efficient plants while tomato, tobacco and beans have photosynthetic rates about half those of the efficient plants. However, in absolute figures the photosynthetic efficiency is relatively low: between 0.5 and 1.3 per cent in temperate areas and 0.5 and 2.5 per cent in sub-tropical regions. This means that only the above-mentioned percentages of the radiation reaching the earth over the growing season is stored by the process. Experts are of the opinion that rates of 5 to 6 per cent are theoretically possible.¹⁸

The rate of photosynthesis depends upon a number of internal and external factors governed by the interaction of light and dark reactions. Among the most important factors, the following can be mentioned: light quality, duration and intensity, carbon dioxide concentration, temperature, water, oxygen, mineral nutrients, in addition to the characteristics of the plant like morphology, age, internal anatomy, photorespiration, light harvesting pigments, pests and diseases and energy dissipation. Experts agree that it is not possible to treat separately the factors affecting photosynthesis but rather they have to be considered in their mutual inter-relationship. This is certainly one of the greatest difficulties faced by scientists in their effort to increase the efficiency of photosynthesis.

The different farming systems developed in different regions of the world attempt to benefit from this biological efficiency and to optimise those aspects of it that have economic relevance.

Agricultural production can be increased either by augmenting the cultivated land or by agricultural intensification which raises land already under cultivation. Agricultural intensification depends on the growth of the plant, the efficiency of nutrient uptaking and conversion, the reduction of their vulnerability, or in other words, the improvement of their resistance and finally, the identification and domestication of new species that can expand the spectrum of useful plants.

The predominant productivity criteria are based on economic considerations of cost minimisation and technological efficiency. These criteria, when applied to agriculture, stimulated the increase of the harvesting material in relation to a unit area in a given time. Yields are expressed in terms of amount of plant material produced in a given period of time, usually one year or one crop period per unit of cultivated area. So, from the economic point of view, the process ends with the production of a given product. But, in biological systems, the process of production is a continuous one in time because the life cycle does not end with the production of the product. Therefore, when measuring productivity, it is important to make a distinction between the biological time of the life cycle of the plant and the economic time to produce harvestable material.

Two concepts should be distinguished: the gross primary productivity and the net primary productivity. Primary productivity is defined as the rate at which the solar radiant energy is stored by photosynthesis in the form of organic substances which can be used as food and raw materials. The concept of gross primary productivity includes the quantity of energy that has been used in respiration by the plants and therefore is not available as material. Consequently, net primary productivity is the rate of storage of organic matter in plant tissues, without considering the energy used in the process of transpiration. It has also been defined as the increase in dry matter per hectare per year.¹⁹

The economic activity attempts to maximise the production of those parts of the crop that can be harvested for economic purposes. For example, in the case of new varieties of cereals, more energy goes into the grains and less into the leaves, roots and stems. Scientific understanding and technological capacities have been the main tool in the achievement of this goal through selection and manipulation of species, changes in the architecture of vegetables, increase in subsidies and so on. In fact, this has been the approach of the Green Revolution. It has been empirically demonstrated in the Netherlands where the adoption of different varieties of winter wheat during the first 50 years of the century evolved with an increasing production of grains and decreasing production of straw.

It is clear that further technological progress in raising economic productivity and yield will be limited by natural causes. This is an important fact because since land is becoming increasingly scarce, the increase in production should be reached through intensification, that is, through more yield per crop and per unit of land.

Swaminathan noted that further increases of about 25 per cent on the harvest index in several crops is still possible by traditional breeding technologies (Table 1). However, in the end, the agricultural efficiency can be improved only through increasing the photosynthesis efficiency. Biotechnology is opening up new genetic possibilities for technological innovations for increasing productivity. This technological development has some employment implications. Past developments had opposite effects on labour requirements. On the one hand, increase in production is supposed to require more labour. However, to the extent that the diffusion of these

varieties takes place in land favourable to mechanisation or in large-scale farms, it is likely to have the effect of displacing labour. On the other hand, the fact that the manipulation of the harvest index reduces the residual of the agricultural process is also likely to save labour and favour mechanisation.

It is extremely speculative to advance opinions concerning the effects on employment of increasing biological efficiency. This kind of new technology based on genetic engineering is unlikely to materialise in the next 20 years or even more, and even then, it will have to undergo the lengthy process of adaptation and diffusion among farmers.

Table 1
Crop yields

Crop and variety	Biological yield (tonnes/ha)	Grain yield (tonnes/ha)	Harvest ¹ index (%)
Rice			
- Deepwater rice	23.2	2.23	0.10
- Tall indica (MTV)	6.13	2.39	0.39
Dwarf indica (TN-1)	9.00	5.03	0.56
Wheat			
Tall strains	11.04	2.92	0.24
Semi dwarfs	12.54	4.89	0.39
Maize			
Varieties	15.2	3.7	0.24
Hybrids	15.5	6.8	0.44

$$1. \text{ Harvest Index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100.$$

Source: M.S. Swaminathan: Integration of the tools of Mendelian and molecular genetics in crop improvement in genetic manipulation of crops, International Rice Research Institute (IRRI), Cassell, Tycooly, London 1988.

3. Productivity, technology transfer and adaptation

An additional aspect concerning productivity refers to the fact that certain environments are more favourable to specific crops than others and that in high-temperature environments and under high-water stress in general, the plant requires greater use of the transformed energy in respiration. This means that larger parts of the gross primary productivity is dedicated to the maintenance of the plant and, consequently, the net primary production is reduced.

This is an aspect which is frequently ignored in the transfer of agricultural technology and in the comparisons made of economic productivity in the temperate, arid, semi-arid, tropical and sub-tropical regions. This extremely important aspect can be illustrated comparing high yield varieties in northern Europe and tropical areas. Biological productivity is highly sensitive to the variation in solar radiation which in turn is associated with the day length. In the Equator, such a variation is practically nil

throughout the year, but in temperate areas the days tend to be longer in summer, that is, at the ripening time, which means that crops benefit from a higher input of solar energy. Besides, in temperate areas, temperature is lower than in tropical areas, and so the plant spends less energy in respiration. In tropical zones, due to higher temperatures throughout the year, plants have high respiration rates (meaning that a large part of their energy is used in respiration reducing the biological efficiency and therefore the economic productivity). These two facts define different crop (potential) productivities in tropical and temperate zones as is indicated in Table 2.

Table 2
Average yields in the temperate areas and in the tropics

Crop	Temperate area (kg/ha)	Tropical area (kg/ha)	Tropical yield as % of temperate yield
Rice	4,109	1,958	48
Wheat	2,984	1,363	46
Maize	3,993	1,351	34
Sorghum	2,270	1,249	55
Soyabean	1,620	1,038	64
Beans (dry)	1,079	640	59
Groundnut	1,667	1,036	62
Potato	18,056	8,704	48
Sweet potato	13,594	6,884	51
Cassava	11,844	9,103	77
Sugarcane	61,190	53,328	87

Source: L.D. Haws, et. al. Comparison of crop productivity in the tropics and temperate zone, in Potential productivity of field crops under different environment, IRRI, 1983.

The concept of potential productivity refers to the maximum yields obtainable with a given amount of solar energy in a given location. Such a potential productivity is in fact the limiting factor for those optimal cases that combine outstanding ecological and climatic conditions with economic capabilities to apply ample amounts of energy subsidies to the soil. However, optimal conditions are rather rare. Different types of stresses impair the achievement of potential productivity. The economic situation of farmers in developing countries has deteriorated and made more serious by debt problems and unfavourable international conditions. The ability of crops to produce high yields under ecological and climatic stress is defined as relative productivity. Thus, technological development can assume two approaches. One is oriented towards the maximisation of yields without modification of the environmental conditions. In this case, plants will be selected for their ability to produce high yields under specific natural conditions. This is the approach adopted in agricultural research which generally poses fewer natural and economic constraints.

A second alternative focuses on the limiting factors of productivity and attempts to overcome them in order to increase relative productivity, or in other words, to reduce the difference between relative productivity and potential productivity. In this case, technological development will be addressed to the reduction of a particular stress or a group of stresses. In

this case, most probably plants will be selected, not only for their capacity to produce high yields, but also for their ability to survive and produce under particular stress conditions. Technological innovation in this second case will be oriented to the factors limiting productivity, e.g. soil acidity, low phosphorous, efficiency for uptaking nutrients and so on and so forth.

To catch up with the levels of production in agriculture in developed countries on the basis of the simple transfer of available agricultural technology has clear limitations, not only due to the limitation posed by the feasibility of the application of energy-intensive techniques but also because the natural conditions of tropical areas impede the achievement of high productivity similar to the levels achieved in temperate zones.

It is in this context that the implications of available agricultural technology and biotechnologies should be examined and assessed. Available agricultural technology is largely based on the possibility of continuously increasing inputs of fertilisers, pesticides, water and mechanical equipment. The genetic varieties can achieve high economic yields if planted in favourable ecological and climatic conditions and supported by a great amount of auxiliary energy input. If the local conditions are less favourable than the conditions where the varieties originated, then this input would need to be larger. These aspects are important to consider in the transfer of new varieties to developing countries.

The above consideration brings us back to the concept of economic productivity. If the productivity is measured not in relation to the cultivated area at a given time but in relation to the energy consumed and the energy required to maintain the system functioning, then the picture is dramatically different. So, while it is true that developed countries, the United States in particular, produce several times more per unit of agricultural land than developing countries it is also a fact that such larger production is obtained at a cost ten times higher in terms of energy.

Almost two decades ago, Odum demonstrated that, doubling of crop yields requires tenfold increase in fertilisers, pesticides and horsepower, and the industrialised agriculture produces four times per acre more than what is produced by a man with the help of animal power in India, but the latter is hundred times as demanding of resources and energy.²⁰ The picture has not changed today. Furthermore, as Leach and Pimentel have demonstrated, energy use in the agricultural sector of the developed countries, is increasing more rapidly than in any other sector of the economy.²¹

The question then arises: are the developing countries in a position to afford such high energy-intensive technologies? The energy requirements will also be greater keeping in mind the more unfavourable physical conditions. Apparently, other strategies should be developed and biotechnology potentialities must be examined precisely in the light of new alternative strategies.

The questions raised above draw attention to an additional aspect that arises from the comparison of the potential productivities, the higher country yield and the ratio of world average yield to highest country yield of certain species (see Table 3).

It appears that the ratio of the world average to the highest country yield is lower in crops like beans, groundnuts, sorghum and cassava. A more careful analysis of the situation also shows that these are the crops that are grown under stress conditions or that receive lower inputs of energy. For example, cassava is cultivated in marginal drought-prone areas of low

fertility and phosphorous and high soil acidity. This implies that it is a crop that has proved to have the capacity to absorb phosphore, is tolerant to acidity and is drought-resistant. The cassava yields are several times the world average when it is grown in optimal conditions.

Table 3
World average yield and highest country yield
of various crops

Crop	World's average yield (t/ha) (1)	Highest country yield (t/ha) (2)	Ratio of (1) / (2)
Rice	2.54	6.96 (Gabon)	0.36
Wheat	1.78	5.73 (Netherlands)	0.31
Maize	2.96	7.44 (New Zealand)	0.40
Sorghum	1.30	4.79 (Spain)	0.27
Sugarcane	55.30	153.4 (Peru)	0.36
Potato	14.50	34.40 (Netherlands)	0.42
Sweet potato	8.40	23.90 (Sudan)	0.35
Cassava	9.10	32.30 (Cook Isl.)	0.28
Sugar beet	32.30	50.00 (Belgium)	0.65
Soyabean	1.51	3.36 (Italy)	0.45
Bean dry	0.57	2.43 (Egypt)	0.23
Groundnut (in shell)	0.98	3.798 (Malaysia)	0.26

Source: A. Tanaka, Physiological Aspects of Productivity in Field Crops, in Potential Productivity, op. cit., 1983.

Tropical areas are reached not only in diversity of useful plants but also in more rich and serious varieties of pathogens and pests. So, in tropical countries useful varieties must compete with a larger variety of indigenous plants, diseases and pests factors that are considered biological constraints to higher economic productivity. Overcoming these difficulties requires larger inputs, hence more energy under the present technological pattern. The magnitude of this additional requirement is difficult to estimate. However, the fact that yield losses of crops due to weeds are calculated around 30 per cent of the potential yield and that this percentage can rise up to 65 per cent in some developing countries, provides an indicator.

CHAPTER III

POTENTIALITIES OF NEW BIOTECHNOLOGIES FOR DEVELOPING COUNTRIES

The previous chapter examined how the application of economic principles of efficiency and productivity was limited by the natural base of agricultural activities. It was also noted that the scope for increasing productivity in agriculture was limited by biological productivity. Thus despite the massive application of the scientific and technological knowledge to agriculture, the basic structure and mechanisms that govern natural phenomena, particularly biological productivity, have remained untouched. New biotechnology represents the most challenging attempt to overcome the limiting factors of agricultural productivity by the manipulation of natural structures and dynamic cycles.

In what follows we will examine how new biotechnology can revolutionise agriculture and food production. We shall also consider the possibilities of the advantageous use of this technology by developing countries.

New biotechnology is likely to dramatically affect the agriculture and food production in developing countries in various ways. In plant agriculture, it will help modify both the natural environment and the genotype, and thus to extend the crop areas and raise biological and economic productivity. In animal agriculture, it will enhance efficiency in animal reproduction, growth and development; and in disease and pest control it will increase the nutritional value of the meat. In food processing, new biotechnology is likely to contribute to better management and utilisation of crop residues and animal waste, to more efficient production of protein and amino acids, and to more productive use of enzymes. New biotechnology may also affect developing countries by creating new products that can displace traditional crops hitherto exported by them.

New biotechnology for increasing biomass production and productivity

In Chapter II we noted that although economic productivity has risen as a result of the application of science-based technology, the biological productivity has not substantially improved. In fact, in the case of most of the major crops (such as wheat and maize) the traditional plant breeding of the Green Revolution has not increased the biomass of the crops over the past 80 years. Rather, there has been a redistribution of it from vegetative parts to harvestable grain. This fact determines a fundamental limit to any attempt at further improvement of economic productivity. In other words, scientific and technological progress has until now been unable to manipulate the basic natural mechanism governing productivity. Plant growth and productivity depend upon photosynthesis, a biological process whose efficiency has remained largely unaffected by technological development. The increasing economic pressure over agro-ecological systems for higher yield from ever diminishing unit of used land has led to attention towards those mechanisms and processes that determine natural productivity.

The scientific community has accumulated a great deal of knowledge about photosynthesis, yet only a minor part of this understanding has been translated into technology. It is expected that new biotechnology will allow a deeper understanding and application for the manipulation of natural photosynthetic activity. This chapter focuses on:

- a) the photosynthesis mechanism itself;
- b) the factors that limit the efficiency of the process mainly water and nutrients used by the plants; and
- c) environmental factors and their interrelationship with plants.

It is expected that new biotechnology can contribute to the increase of biomass production in two ways: firstly, by improving the absolute net rate of photosynthesis and secondly, by extending the time over which optimal photosynthesis is carried out. More specifically, the enhancement of photosynthesis can be achieved by the identification and control of the mechanisms that regulate wasteful process, in particular photorespiration which can reduce crop yield by as much as 50 per cent.

The practical application of methods for the improvement of photosynthesis is still at a very early stage. It is dependent on the identification of the individual genes, the selection of DNA or RNA, their incorporation into a suitable vector, stabilisation of the new DNA in the genome of the new host and so on. In this process, other biotechnologies like tissue culture, protoplast fusion, and single gene transfer can be applied.

New biotechnology and nitrogen inputs in agriculture

Bacteria, plants and animals, and, in general, all forms of life cannot grow and function without nitrogen. Nitrogen is a rather abundant element in the air: it actually represents four fifths of the air. Paradoxically, it is recognised that the availability of nitrogen is one of the main factors limiting plant growth and agricultural expansion, the other being water. The problem is that neither man, animal nor plant can use molecular nitrogen. It must be fixed first, that is, combined with other elements such as hydrogen, carbon and oxygen, forming in particular, nitrate or ammonium salts.

According to FAO, after land and water, fertilisers are probably the most important input accounting for increased yields. Between 1965 and 1976 they were responsible for about 55 per cent of the yield increases in developing countries. Fertilisers are substances that provide extra nutrients into the cycles of plant growth and decay, replace the extracted nutrients of the soil (by crops) or simply provide additional ones in order to achieve higher yields. Nitrogen, phosphore and potassium are considered the major plant nutrients, and among them nitrogen is the most important. According to FAO, the world as a whole uses about twice as much nitrogen as phosphore or potassium. This relevance is even greater in developing countries where the ratio between nitrogen and phosphore is 1:0.36. Although the importance of nitrogen input in plant agriculture is very well known since ancient times, the most significant technological breakthrough in this matter has been synthetic fertiliser production associated with the oil industry. Today chemically-fixed nitrogen is probably the largest single input into agriculture and it is responsible for up to 35 per cent of the total productive capacity of all crops. However, it is also the most costly single industrial input. The consumption of nitrogenous fertiliser is concentrated in developed countries. Furthermore, cash crops such as wheat, sugarcane and oil seeds, etc. receive the major amounts of fertiliser nitrogen whereas food crops require very little of it. It is necessary to increase the use of nitrogen in agro-ecological systems to overcome low agricultural productivity and food problems in developing countries. The possibilities to meet this requirement by increasing consumption of chemically-fixed nitrogen are however increasingly dim. In developing countries, the industrial fertiliser requirements are met mainly by imports from the developed countries. But the critical balance of payments situation, growing indebtedness and deteriorating terms of trade suggest the need for a domestic solution.

However, nearly 80 developing countries do not have a sufficient domestic market, nor locally exploited raw materials to justify a costly fertiliser industry. These are mainly agricultural countries but they account for not more than 5 per cent current fertiliser markets of the developing countries. Few countries endowed with raw materials are in a position to build up export-oriented fertiliser industries - actually very few of them can justify the establishment of a fertiliser industry on the basis of their domestic market. The situation is rendered even more difficult by uncertainty regarding oil prices.

Until recently, the alternative to "chemical", industrial or inorganic nitrogen was the use of organic materials (either as organic fertilisers or organic manure). An alternative to the energy-intensive chemical fertiliser is the use of organic materials on a large scale, frequently in combination with multiple cropping (and intercropping) systems. The long-term benefits of this system are quite abundant. However, immediate economic gains from the use of organic materials as fertilisers do not compare very favourably with synthetic or inorganic fertilisers.

The annual world consumption of fertiliser grew from about 0.4×10^6 tonnes in 1905 to over 50×10^6 tonnes in 1982. If no new technology involving nitrogen input is developed, it is estimated that 160×10^6 tonnes of nitrogen will be required by the end of the century. This is why the need to exploit on a large scale, the potential of biological nitrogen fixation is becoming urgent. It is in this context that new biotechnology is expected to help.

In nature, certain micro-organisms and algae have the capacity to synthesise nitrogenous compounds required for their functioning and growth. Animals and man that do not have this synthetic capacity acquire the required nitrogen by direct or indirect consumption of protein originally synthesised by plants. The natural process of biological nitrogen fixation is not sufficient to provide the food requirement of the society. So natural nitrogen fixing organisms are supplying an estimated amount of 175 million tonnes of nitrogen annually or about 70 per cent of the total requirements, the remaining part being produced in chemical fertiliser plants through the use of modern technology. The possibilities to increase agricultural production depend on the ability to improve the natural process of biological nitrogen fixation and/or the possibilities to increase the efficiency of the chemical process of fertiliser production and utilisation.

The biological fixation of nitrogen is accomplished by few micro-organisms; some of them fix the atmospheric nitrogen under free living conditions while others need the symbiosis with other organisms that generally provide the energy required for the process. To sum up, the nitrogen to agriculture is supplied by biological processes or through the artificial production of fertilisers.

The natural biological fixation can be done in symbiotic systems or by non-symbiotic mechanisms. The non-symbiotic or asymbiotic nitrogen fixation is realised mainly by blue-green algae and by free-living nitrogen-fixing bacteria.

Different, although complementary approaches can be identified in current activities related to biotechnology applications for increasing nitrogen fixation. To a great extent the applicability of these approaches depends on the local agro-ecological conditions. One approach is based on the enhancement of natural biological nitrogen fixation through traditional techniques upgraded by the application of new scientific knowledge. Basically

the approach is to maximise the use of micro-organisms to ensure soil fertility and save energy. The second approach includes genetic engineering either for the improvement of the traditional techniques or for generating new technologies. In this second case, current research is concentrating on three approaches. One is designed to raise legume crop yields through the application of genetic engineering to improve the capacity of bacteria to fix nitrogen. A second more long-term approach is to insert directly into the plant crop the genes responsible for nitrogen fixation. And finally, an even more ambitious objective is to use genetic engineering to allow plants like cereals (which at present must rely on chemically-fixed nitrogen) to fix nitrogen in symbiosis with bacteria or even directly. In other words, what is pursued is the transfer of nitrogen fixing genes to non-legumes.

Microbial inoculant technology

For centuries farmers cultivated legumes. Their empirical knowledge indicated that the plant was not only rich in protein, but also that it required, little if any, additional fertiliser and that continuous growth of legumes in one area leads to improved soil fertility. Thus planting legumes in fields that have previously been used for other crops restores the fertility of the soils. The scientific reason is the existence of a particular bacteria, called rhizobia, which fixes nitrogen in nodules in the roots of leguminous plants, so that it helps to reconstitute to soil the nitrogen that has been extracted by crops.

Therefore, it is not strange that for thousands of years different species of legumes like beans, peas, soyabean, cowpea, lentil, groundnut, chickpea, clover and alfalfa, have been grown extensively in tropical and sub-tropical areas providing valuable sources of food and fodder. In this context, there are about 18,000 leguminous species of which only a few (less than 100) have been domesticated and used by man. It has been estimated that at present legumes in association with rhizobia fix at least 35 million tonnes of nitrogen yearly valued at more than US\$10 billion. Nevertheless, legumes obtain only 25 per cent of their nitrogen from nodulisation, while the remaining 75 per cent is obtained from the nitrogen already fixed and existing in the soils in the form of nitrate and ammonium salts. Therefore, at present the limiting factor for leguminous growth is the present 25 per cent of nitrogen fixation through nodulisation.

A second aspect related to the fixation of nitrogen is that, particularly with grain legumes, the season for active nitrogen fixation in the nodule is relatively short. A third aspect to consider is that forage legumes fix more nitrogen than do grain legumes because the development of larger seeds implies a larger demand for carbohydrate than does that of smaller seeds.

Finally, a major limitation arises from the specificity of the rhizobium-legume symbiosis and their local climatic and soil conditions. In other words, there are specific strains of rhizobia that work well with a particular legume host and not with others, because their efficiency also depends on the ecological conditions which vary according to geographical location.

Thus, these are several possibilities for increasing food production on the basis of the potentialities of rhizobium-legume symbiosis; in particular, through the capacity of rhizobia to fix nitrogen. These possibilities range from the expanding use of legumes (which indeed imply recovering for the legumes the position they enjoy in the world food pattern) to the application of genetic engineering. During the last three decades a process of substitution of legumes rich in protein (40 per cent) for cereals low in

protein (10 per cent), has occurred. This process is associated with the adoption of particular patterns of consumption. Between these two extremes, it is possible to consider the identification and promotion of additional legume species not yet domesticated, the inoculation with rhizobia, the improvement of legume-rhizobium symbiosis, and the nitrogen fixation in the nodules in order to increase the already-mentioned 25 per cent capacity and, finally, to apply genetic manipulation for the creation of genetic varieties that can fix the nitrogen they need. Crops at present not able to do it are, among others, cereals.

Of the 18,000 leguminous species only 20 are used extensively in spite of the fact that nutritionally they are two to three times richer in protein than cereals grain and some of them like soyabean and peanuts are also rich in oil, let alone their importance for the maintenance of soil fertility. According to the US National Academy of Sciences a leguminous crop can add up to 500 kg of nitrogen to the soil per hectare per year.²²

The emphasis on cereal production contributed to the reduction of land allocated to legumes - a product that has a lower price in international market but a higher protein content. This means that the protein supply in developing countries can be achieved by an increase of the acreage dedicated to leguminous cultivation and their inter-cropping with non-legume crop. Besides the advantage of a crop of higher protein content this approach reduces the need for inorganic fertiliser and hence dependence on industrial inputs and costs. It also increases employment since inter-cropping systems are not easily mechanised (in other words, they are labour-intensive). This approach can be complementary to the identification, selection and diffusion of leguminous plants at present scarcely known or under-utilised.

Table 4
Nitrogen fixed by Rhizobium legume association

	Nitrogen fixed (kg/ha/year)	Estimated value as fertiliser at 1975 prices (US\$/ha)
Alfafa	128 - 300	38 - 90
Clover	118 - 155	35 - 47
Cowpea	84	25
Faba bean	240 - 325	72 - 98
Lentils	103	31
Peanuts	47	14
Soyabeans	60 - 80	18 24

Source: National Academy of Sciences, Microbial processes promising technologies for developing countries, Washington D.C., 1979.

The fact that certain bacteria in the roots of legumes were able to fix nitrogen has (since the last century) motivated the practice of artificial inoculation with rhizobium. Two methods can be used: soil inoculation, which consists of putting effective rhizobia near the seed in order to increase the chance that the seedling can be nodulated by the bacteria in a short time. In this case, it is important that a sufficient quantity of bacteria can be used and that bacteria can survive until the soil conditions permit an adequate development of the plant roots and their infestation. The main problems with inoculants is that they are perishable, that the use of fungicide and pesticide to preserve the seed acts as inhibitor or even kills the rhizobium. They are not adequate for dry soils, where they normally die before there is enough moisture to permit germination. A particular aspect of these inoculants is that each plant has a particular rhizobia and that specific local ecological and climatic conditions must be fulfilled. Thus either the inoculant is less efficient than the native bacteria, or it is able to infest the first crop but does not survive to infest the following planting.

Therefore, the production of inoculants is locally conditioned, and the possibility of this production on a large scale depends on the commercial type of culture like soyabean. In the United States about 30 million acres of soyabeans are inoculated every year. The annual nitrogen fixation in soyabeans in the United States is estimated at more than 110 kg per hectare valued at about US\$375 million. The advantages of inoculation are: it requires little capital, the transport costs are minimal and the technique itself is relatively simple and can be easily applied in rural areas of developing countries. Furthermore, it can be done in accordance with the local requirements and can also generate a few additional jobs.

The natural fixation of nitrogen through the application of inoculants of selected strains of rhizobia is an economic and environmentally-sound alternative to the industrial chemical fertilisers. It allows cost reductions at farm level and reduction of imported fertilisers. It is oriented to a more natural process of fertilisation which reduces water and soil contamination and hazards to human beings and animals. The technique is based on the introduction of pre-selected strains of rhizobia suited to the specific crop into the soil in the vicinity of the emerging roots or together with the seeds. The strain selected must have competitive advantages over any indigenous strain of rhizobia. It should also be able to persist in the soil after the host crop has been harvested in such a way that a following crop, not necessarily a legume, can benefit from the fixed nitrogen. Finally, it should have the capability to nodulate and to fix nitrogen under a wide range of soil temperatures and be tolerant to acid soils.

One of the important considerations is that rhizobia inoculants should be tailored to each specific crop and environmental conditions. Furthermore, rhizobia inoculants are very sensitive to storage and shipment. Besides the United States, commercial production of rhizobia inoculants takes place in Australia, Argentina, Brazil, Egypt, India and Uruguay.

Some case studies

1. The production of rhizobial inoculant in Brazil

Soyabean was introduced in Brazil about 20 years ago. Ever since Brazil has become the world's second largest producer and exporter of soya protein. During the first 10 years, however, the soya cultures treated with rhizobia imported from the United States, did not produce any important result, a demonstration of its high specificity in relation both to the crop variety and to the ecological and climatic conditions. In 1965, facing the failure of the

transfer of the inoculant technology on soya production, the state-owned Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) initiated the process of identification of indigenous strains and their reproduction for the production of inoculants. The purpose was to replace imported chemical fertiliser that represented about 75 per cent of the total cost of production of soya. The experiment has been successful and already in 1981 the 4.5×10^6 hectares under soya cultivation use only locally-produced rhizobia inoculant. It is estimated that in 1981 the use of rhizobia inoculant in soya cultivation saved the equivalent of US\$1,000 million of chemical fertilisers. Furthermore, the soyabean crop has been used to expand the agricultural frontier by the incorporation into agriculture of edaphic savannas called "cerrados". This means that the soya expansion in Brazil has not displaced other crops.²³

The technology of rhizobia inoculant involves the following steps:

- selection of the appropriate more effective strain of rhizobia, in terms of nodulisation and ability to fix nitrogen, compatible with the crop;
- Enlarging the scale of selected strain through adequate culture in fermentation process;
- incorporation of the obtained strains into an adequate carrier material that facilitates its transport, packing and manipulation; and
- coating the crop seed with the inoculant or introduction of the inoculant directly into the seed.

In Brazil, the identification and first reproduction of the strains of rhizobia is done at the EMBRAPA laboratories, the tested strains of rhizobia of proven efficacy in inducing better nodulation, nitrogen fixation and yield are distributed by EMBRAPA to seven plants registered at the Ministry of Agriculture for mass production of rhizobial inoculants. The overall capacity of these plants is eight million dosis per year of which not more than one per cent are for cultures other than soya, mainly beans (feijao) and peanut. The larger company has a capacity for three million dosis of inoculants per year. According to Brazilian experts, the production of rhizobia inoculants can be greatly improved by better control and more efficient fermentation in order to avoid their contamination.

Quality control at the factory is of great importance for successful use of microbial inoculant, particularly for rhizobial inoculant. In India, the ISI has developed standards for rhizobium²⁴ prescribing the characteristic of the inoculant itself as well as the environmental conditions and periods of time (storage conditions, temperature, expiry periods, etc.) to be observed for its effective use. This aspect is even more relevant under tropical conditions prevailing in developing countries.

A particular problem is the seasonal aspect of the inoculant production which results in long idle periods of the fermentation equipment. This problem can be partially solved by the expansion of production to other inoculants. The Brazilian inoculant market is potentially very large since it is not limited to soya but includes also the black bean (feijao, which is the main staple of the Brazilian diet), peanut, legume-based pastures, including the legumes for under-used savannahs, forestry, etc. The Brazilian production of feijao is of about two million tonnes per year on an area of 5.3 million hectares and the production of peanuts is about 300,000 tonnes per year on an area of 220,000 hectares.²⁵

In the case of fodder the use of inoculants is still negligible. Yet this is probably one of the most promising areas for the application of inoculants since it has not only direct effects on the saving of fertilisers and raising of production (hence saving also of agricultural land) but also indirect

effects on the productivity of animal production. FAO has noted that the dramatic increase in meat production in Uruguay has consequences for the strong improvement of the pastures, particularly clover, inoculated with rhizobium.²⁶ The inoculation of clover with improved strains of rhizobia can increase yields from less than 500 kilos of dry matter per hectare to over 2,000 kgs per hectare.²⁶

The final possible application of the technology is for reforestation and afforestation. At present the reforestation programmes in Brazil focus on the use of leguminous species of rapid growth like leucaena, carob, jacaranda, casuarina. The reforestation with these species is not only more advantageous because of its more rapid growth than the traditional species like eucalyptus, but also because they use much less water. In addition, they produce forage (which is not the case of the eucalyptus). In 1982, EMBRAPA initiated the production of rhizobial inoculant for the carob on an experimental basis in order to use it in the forestation programmes of the Nordeste and to recover areas affected by erosion. The production of inoculants has also been initiated in the case of beans. In this case the main difficulty is the identification of the most appropriate strains since the varieties of beans used are relatively large. So are those of the rhizobia strains.

It is important to note that the use of inoculant saves capital but not labour. This is for two reasons: first, the inoculant replaces nitrogen but not other fertiliser and secondly, the inoculant should be coated with the seed of the leguminous crop; this is a task that, in Brazil, is done practically on the field and is little mechanised. Furthermore, when the legume culture is used to fix nitrogen for a following crop that has no fixing ability, say for example, cereals, or whenever a mixed-cropping system is adopted, the mechanisation is rather problematic and therefore the net impact of the inoculant technology is likely to be more positive in terms of labour requirements. This labour impact does not consider the creation of new, although limited and skilled demand for labour in the manufacture of the inoculant. The operation of the inoculant plant requires professional and well-trained staff on fermentation processes. Besides indirect impacts are associated with the increasing areas that can be reclaimed through the forestation programmes with legume species, or recovery of eroded land.

Since the type of fertilisation and methods to apply differ from other traditional fertilisers the need for extension agents, written material and training has been demonstrated in the case of Brazil. The Brazilian experience also demonstrates that:

- legume cropping permits sustained productivity in tropical areas, especially when fertilised with the appropriate strain of rhizobia;
- specific legume and appropriate strains of rhizobia would help increase the use of at present under-utilised savannah areas (as in Brazil);
- leguminous tolerant species can be extremely useful in forestation programmes, providing energy for the local communities and fodder for animals;
- inoculant technology would contribute to forestry and reforestation programmes in arid and semi-arid areas with indigenous species.;
- inoculant technology is well adapted to inter-cropping and multi-crop small farming systems typical of many developing countries;
- it is a very specific technology and its development contributes to self-reliance of rural areas;
- the technology contributes to the reduction of energy-intensiveness of the modern agricultural technology;
- the production of inoculants would be extremely important because legumes are a basic component of the diet of developing-country populations;

- the improvement of the productivity of local legume production will contribute to solving the nutritional problem of developing countries considering that the protein content in legumes is several times higher than in cereals (30 per cent and 6 per cent average respectively); and
- finally, the economic advantages in terms of foreign exchange saving and its impact on the overall reduction of the cost of production should not be minimised.

On a more long-term basis, the increasing knowledge of genetic engineering offers the possibility to manipulate the symbiosis itself by acting either on the rhizobia or on the plant host. For example, one approach is to increase the photosynthetic capacity of the plant which in its turn will provide more energy to the rhizobium. Another approach is to improve the strains of rhizobia increasing their capacity to fix nitrogen.

Other developing countries (e.g. Argentina, Uruguay and India) have also made successful experiments in the production and use of rhizobial inoculant. In India, seed inoculation with rhizobium in rain-fed conditions has resulted in average increases of yields of 27 per cent for chickpea, 26 per cent for pigeon pea and 38 per cent for mung bean.

A second natural process of fixing nitrogen through symbiosis is between an organism called frankia and non-leguminous plants, mainly woody shrubs and trees. At present about 145 species of plants of this type are known. Among the most important of these plants are the casuarina. In Senegal soil around casuarinas, the nitrogen increased at rates of about 60 kg per hectare.

2. The use of azolla and blue green algae in China, Egypt and India

The third natural process of symbiotic fixation of nitrogen occurs by the association of the freshwater fern called azolla and a blue green algae (BGA) known as anabaena. This association is one of the most efficient processes of nitrogen fixation from the energy point of view. The association permits the harvesting of solar energy, its conversion through photosynthesis and its utilisation for the nitrogen fixation. For centuries, this association has been used for the production of green manure and forage in China, India and other Asian countries. The azolla-anabaena symbiosis can fix between 100 and 150 kg of nitrogen per hectare per year in approximately 40 to 60 tonnes of biomass, if multiple crop growth cycle of the association is practised over a year.²⁷ This amount of biomass can be achieved because under favourable conditions azolla vegetation can double in about five days. However, the normal amount fixed is between 50 and 75 kg/hectare per crop and can be achieved with active growth period of six weeks.

Dried azolla decomposes in the soil releasing 56 per cent of the nitrogen compound in three weeks which then becomes available to the plant, normally rice which is intended to fertilise. One crop of azolla applied to paddy rice is equivalent to the application of 30 kg/ N_2 per hectare of urea (see Table 5).²⁸

Azolla is suitable for double cropping of rice in irrigated areas. It is believed that yielding 75 per cent of the N fertiliser required adequate selection of strains that can multiply more rapidly and can withstand extreme temperature which could result in the increase of the azolla efficiency. An additional advantage of the azolla derives from its high protein content. For this reason, it represents an important source of feed. In China azolla has been used up to a 50 per cent in the diet of pigs and one hectare of green azolla provides enough fodder for 200 pigs.²⁹

The non-symbiotic natural fixation of nitrogen at present being investigated and applied refers to the utilisation of blue green algae (BGA) and the free-living nitrogen fixing bacteria.

The blue-green algae is a self-supporting organism able to harvest the energy it requires directly from solar energy through photosynthesis. It withstands extreme temperatures depending on each species, fixing nitrogen in desert areas as well as in fresh waters.

Inoculation of paddy rice with blue-green algae is widely used in Egypt and India where blue-green algae can contribute up to 77 kg/ha/per cropping season. In the USSR, inoculation with BGA resulted in increases of rice yields by 13-20 per cent while in China a 24 per cent yield increase was achieved.

Table 5
Effects on grain yields of azolla incorporation
compared with application of chemical nitrogen fertilisers

TREATMENT	Grain yield (1979)	Tonne/ha (index) (1980)
No nitrogen	2.6 (100)	3.2 (100)
Nitrogen (30 kg/ha) from area ¹	3.2 (122)	3.8 (123)
Nitrogen (60 kg/ha) from area ¹	3.7 (141)	4.2 (139)
Azolla growth before transplanting	3.2 (122)	4.0 (123)
Azolla after transplanting and incorporation	3.1 (118)	3.9 (123)
The same as no. 5 but not incorporated	3.1 (119)	4.0 (123)
Nitrogen (30 kg/ha) plus azolla before transplanting	3.7 (143)	4.4 (140)
Nitrogen (30 kg/ha) plus azolla after transplanting	3.5 (134)	4.4 (140)
Azolla before and after transplanting	3.6 (139)	4.2 (137)
Number of sites	13	19

Source: M.S. Swaminathan (1982) "Perspective of biotechnology research from the point of view of third world countries" in Priorities of Biotechnology Research for International Development - Proceedings of a workshop, BOSTID, National Academy Press, Washington D.C., 1982.

The studies carried out in Egypt and India demonstrated that the inoculation with BGA is equivalent to the application of 24-48 kg/N/hectare, with the additional advantage that algalisation leads to increases in the organic matter component of the soil, hence augmenting its fertility. As in the case of the rhizobium, the BGA presents some local characteristics. The

BGA used for the inoculation should be from the same area where it will be applied. The inoculation of paddy rice with BGA was initiated in Egypt during the 1950s, it was planned to inoculate 21,000 hectare in 1985 and to reach 420,000 hectares by 1990. The inoculated fields gave 26 per cent higher yields than those without inoculation. This process resulted in increasing returns to the government which produces the inoculants for selling to the farmers. Farmers obtain higher returns due to a reduction in the use of chemical fertiliser from an increasing yield obtained. The returns to the farmer are calculated at a rate of 1.48 as indicated in Table 6.³⁰

In India the Agricultural Research Institute provides to the peasant starter culture of BGA. It was calculated that from an area of 25 m² it is possible to obtain, every 15 days, about 100kg of algae that can be used in rice paddy. The inoculation of 10kg/hectare of BGA supplemented with phosphate results in a benefit of between 20 to 30 kg nitrogen/hectare per season. The response in terms of crop productivity has been positive, reflecting increases between 9.3 per cent and 11 per cent in the states of Madhya Pradesh and Tamil Nadu respectively. An additional advantage of the BGA is that it can be stored in dry form without losing its reproductive capacity, so that the dry material can be used at a later date directly in the paddy fields or for new algae production.

Finally, another possibility refers to the inoculation of sorghum, millet, barley, rye and tropical grasses with a particular bacteria known as *asospirillum* which not only has the ability to fix nitrogen but also secretes substances that promote plant growth.

Field experiments in India reveal very encouraging results as is shown in Table 7.

Future developments in biotechnology for nitrogen fixation

During the last two decades increasing efforts have been made to study biological nitrogen fixation. In this process, two different phases have been developed. During the 1960s advances were made in the understanding of the biochemistry and physiology of nitrogen fixation, whereas in the 1970s efforts were increasingly directed towards their genetic aspects. The advances achieved in biotechnology research, in particular cell and tissue culture and genetic engineering, are at present being applied to improve the biological process of nitrogen fixing.

To overcome the nitrogen limiting factor in agriculture and to increase the efficiency in energy consumption and raise yields, are objectives that can be pursued along several paths ranging from the most simple manipulation of living organisms through the application of the scientific understanding of their potentialities and constraints, to the application of sophisticated methods of genetic engineering.

In the short term, the most important impact of new biotechnology should be expected from their application for the enhancement of already known and applied microbial technique and its larger diffusion.

Since legumes are rich in protein and capable to fix nitrogen through their association with particular micro-organism, it seems logical to pay attention to them first. It is clear that the shift from the legume consumption towards the consumption of cereals was associated with a particular pattern of consumption that does not necessarily respond to ecological, climatic, cultural and historical characteristics of different developing countries. Therefore, attempts to reverse this trend can result in

Table 6
Economic returns to the government and rice farmer in Egypt

Economic value	Fertilisation by mineral-N (40 kg N/feddan)		Fertilisation by 100 gm BGA & 20 kg mineral-N/feddan		Total economy
	Tonne/feddan	E.£/feddan	Tonne/feddan	E.£/feddan	

A. For the Government					
Value of the mineral-N units	-	16.200	-	8.100	-
Value of algae inoculant	-	-	-	1.000	-
Total cost of fertilisation	-	16.200	-	9.100	-
Economic return from fertilisation	-	-	-	-	7.100
Average of total yield (paddy)	2.549	-	3.218	-	-
Yield of seeds (white rice)	1.784	-	2.252	-	-
Price paid to the producer	-	151.640	-	191.420	-
Selling price to the consumer	-	249.670	-	315.280	-
Economic return from the yield	-	89.120	-	123.860	25.740
Total economic return	-	-	-	-	32.840

B. For the farmer					
Value of mineral-N units	-	10.360	-	5.180	-
Value of algae inoculant	-	-	-	1.000	-
Total cost of fertilisation	-	10.360	-	6.180	-
Economic return from fertilisation	-	-	-	-	4.180
Average of total yield (paddy)	2.549	-	3.218	-	-
Yield of seeds (white rice)	1.784	-	2.252	-	-
Average of selling price	-	167.981	-	212.048	-
Economic return from the yield	-	-	-	-	44.067
Total economic return	-	-	-	-	48.247

Notes for estimating the above economic study

1. Rice plants are fertilised by 40 kg N as ammonium sulfate/feddan.
2. Nitrogen fixing capacity of the algae inoculant (100 gm/feddan) is 20 kg N/feddan.
3. The value of N-unit is E.£0.405 for non-subsidised price and E.£0.259 for subsidised price.
4. The cost of the algae inoculant production is E.£1.00 and it is the same as the selling price for the farmer.
5. The yield of white rice is 70 per cent of the total yield of paddy.
6. The average yield of algalised rice is E.£3.218 tonne/feddan.
7. The average yield of non-algalised rice field is 2.549 tonne/feddan.
8. The price paid to the producer by the Government is E.£85/tonne.
9. The selling price to the consumer fixed by the Government in the local market is E.£140/tonne.
10. The average selling price to both consumer and Government by the farmer is E.£94.160/tonne.
11. One feddan is equal to 4200m².
12. One E.£ is equal to about 1 US\$.

Source: M.N. Alaa El-Din and S.N. Shalan (1984), The Utilisation of blue green algae for increasing soil fertilisation, Agricultural Research Center, Giza (Egypt), 1984, (mimeo).

Table 7
Potential benefits of inoculation with azospirillum of sorghum,
pearl millet, finger millet and barley in India
 (All India coordinated field trials)

Crop	Yield increase (per cent)	Saving in nitrogen (gN/ha)
Sorghum	9 to 30	40
Pearl millet	4 to 83	13 to 20
Finger millet	2 to 31	13 to 20
Barley	15 to 26	40

Source: N.S. Subba Rao: Nitrogen fixation: Can it be exploited? in Agri-energy Round Table, Washington D.C., 1984.

a more efficient utilisation of agricultural potentialities in developing countries.

A second method is to achieve increasing efficiency in nitrogen fixation, at present obtained by leguminous rhizobium symbiosis which can result in a more efficient agricultural system. It is known as the existence of different strains of rhizobium with different capabilities to fix nitrogen and that rhizobium efficiency is affected by different biological stresses like soil acidity and alkalinity. Thus acid soils, in particular in tropical regions, constitute a major constraint to legume expansion. Rhizobium is also sensitive to drought as well as to high temperatures. Efforts are oriented towards the identification of strains of rhizobium, tolerant to acidity, and to extreme temperatures as well as to salinity and alkalinity. The identification and selection of these strains will permit the preparation of inoculants with the most suitable strains. Work in relation to high temperature-tolerant rhizobia for tropical inoculants is carried out at the International Institute of Tropical Agriculture (IITA) in Ibadan (Nigeria).

The preparation of inoculants at a farm or regional level is a useful activity to promote because it responds better to the local conditions, it can create a new activity and it generates favourable attitudes among peasants for further technological developments. In this context, the important role of the UNESCO Microbiological Resources Centres (Mircens) and of the international research centres like IITA, CIAT, IRRI, etc. should be noted. Similar approaches can be adopted for other nitrogen fixation organisms. In the case of blue-green algae, the limiting factor appears to be the phosphorous and iron content of soils. Therefore the development of practices that combine the utilisation of blue-green algae with phosphorous applications to soil would result in an increase in efficiency in nitrogenous fixation.

The selection of legumes more responsive to microbial inoculation will increase the economic productivity, together with genetic selection of rhizobium and more efficient production and handling of inoculant. Together with the inoculation of cereals and tropical grasses, it will contribute a greater benefit to Third World agriculture.

The economic impact of this short-term strategy in developing countries would be considerable. The potentiality of the Brazilian microbial inoculant

market has already been noted. In Argentina, the potential market for rhizobial inoculant is estimated at US\$10 million. Finally, the potentialities of Indian agriculture to absorb microbial fertiliser is illustrated in Table 8.

The increasing utilisation of shrubs and trees able to fix nitrogen should be promoted in developing countries, since it permits the recovery of deteriorated soil, the incorporation of new land into agriculture and the production of forage which is an important source of renewable energy. A positive impact on job generation can be visualised from a programme that integrates the use of the above-mentioned species for forestation, production of inoculants, and production of fodder and firewood.

Table 8
Requirements, present capacities and shortfalls in annual
microbial inoculant production in India

Crop/microbial	Total acreage (ha x 10 ⁶)	Minimum recom- mended rate of microbial ferti- liser application (kg ha ⁻¹)	Total requirements (kg x 10 ⁶)	Current estimated production (kg x 10 ⁶)
Grain legume/rhizo- bial inoculation	30	0.5	15.0	0.8
Pearl millet/azospi- rillum inoculation	16	0.5	4 x 10	nil
Sorghum/azospirillum inoculation	16	0.5	8.0	nil
Rice/blue green algae	40	10.0	400.0	0.04

Source: N.S. Subba Rao: Nitrogen fixation: Can it be exploited? Op. cit.

The next target in the medium term is to apply genetic engineering and biotechnology developments in order to improve the nitrogenous fixation of rhizobium. A more ambitious approach is the application of genetic engineering to obtain new legume varieties that enhance the symbiosis activity with rhizobium. The improvements on the anabaena-azolla symbiosis for paddy rice should also be considered.

An ambitious approach in the long term is to improve nitrogenous fixing of non-leguminous major plant species in particular cereals. The possibility exists for the modification of a nitrogen micro-organism so that it can live in symbiosis with a different host e.g. rice or wheat. This approach will probably require also modifications in the host plant. A second approach being explored is the modification of some bacteria that already live in the roots of the cereals in order to enable it to fix nitrogen, thus also benefiting the host plant. The transfer of a gene to a crop plant is also being considered. This case implies the transfer of a gene from a bacteria to a plant, that is, from a living micro-organism, characterised by the absence of nucleus, to a high-level organism: a plant in which DNA is packed inside a

nucleus. Important experiments in this field have been carried out with rice at IRRI, working with hybrid production and protoplast fusion techniques.

Finally, the third approach consists in the development of a new variety of cereals able to fix directly the nitrogen that needs the incorporation of the nitrogen fixation genes into the cell of the plant. This approach is certainly more ambitious since it implies the transfer of genes from a bacteria into a plant. In this case the problem is rendered more difficult by the fact that around 17 nitrogenous-fixing genes have been identified in the fixing nitrogen bacteria; thus requiring an enormous capacity of genetic manipulation.

To fix nitrogen is an energy-intensive process for the plant variety. Because the plant should divert part of its energy to it, reducing the part needed for its growth, therefore resulting in lower yields estimated at as much as 20 per cent or even 30 per cent. Whatever process is selected, it appears that the one oriented to improve the nitrogenous fixation of the azolla and its utilisation on rice culture and the legume rhizobium symbiosis will require, given the present state of the art, between three and ten years while it will take between three and five years to improve the inoculant technology. Longer time (five to ten years) is needed for the development of stress tolerant varieties of rhizobium, while between ten and 20 years are needed for the genetic engineering of legumes allowing them to fix nitrogen simultaneously. According to experts, to incorporate nitrogen fixing systems in cereal crops is unlikely to be achieved during the next decade.

New biotechnology to overcome soil constraints

Together with nitrogen other nutrients are important for the plant growth and for increasing yields. The most important, after nitrogen, is phosphore or triple superphosphate which contains about 20 per cent P. In relation to this fundamental agricultural input developing countries confront three basic problems: viz. poor soils, low consumption of industrial phosphorous and inherent inefficiency of phosphorous absorption by crop.

It is known that tropical soils are usually deficient in phosphorous, particularly those areas with low organic matter like much of the Sahel or areas which are intensively cultivated for long periods. In fact, 90 per cent of South American soils are deficient in phosphorous. Therefore, the addition of industrially-produced phosphate is required to maintain or increase yields.

But developing countries consume very little phosphorous. In 1984-85, world consumption was 33.2 million nutritent of tonnes of which 11.7 million tonnes was in developing countries, distributed as follows: Asia, 9.2 million tonnes; Latin America, 2.4 million tonnes; and Africa, 1.2 million tonnes (the last figure is however misleading since Egypt and South Africa together consume 50 per cent of all fertiliser consumed in Africa). The disparities are even larger when compared in terms of quantity of inputs per unit of cultivated area. Thus, while in West Europe the consumption is 36 kg/hq of P₂O₅; in Africa it is only 0.5 kg/hectare.

Finally, the use of phosphorous in agriculture is inefficient. In the United States, less than 35 per cent of applied phosphorous and potassium are recovered by crops. The global rate is calculated at about 20 per cent. This percentage is even lower in developing countries and, in particular in tropical soils and arid and semi-arid lands. In these cases, crops utilise less than 10 per cent of the applied phosphorous due to the rapid transformation of phosphate into different forms. The phosphore that has not been taken up by plants is immobilised by chemical reactions in the soil.

This means that a great part of phosphore applied as fertiliser in agricultural lands has not been used and is still there and available depending on the capacity of the plants to take it up. The economic importance of this phenomenon should not be underestimated. It can be appreciated by the simple fact that one tonne of wheat and one tonne of rice take up 20 kg and 25 kg respectively of superphosphate.³¹ New biotechnology is expected to contribute to overcoming this inefficient pattern.

The technology of mycorrhizal inoculation for increasing uptake of P is still at a very preliminary stage. It is employed on an experimental basis but has not yet become an agricultural practice. In most cases, it is based on the collection of soil from areas forested with trees already infested with the fungus, a process which is extremely cumbersome. It is calculated that two to three tonnes per hectare of inoculant would be required.

Studies and field experimentation with mycorrhizal inoculation are being carried out at the Centro internacional de agricultura tropical (CIAT) in Cali, (Colombia) in relation to the potential implications for cassava production and pasture in acid soils. Actually, it is well-known that the ability of cassava to grow well on low phosphorous soils is due to the association of its roots with mycorrhizal fungi. Furthermore, trials indicate that the increase in dry weight of pastures inoculated with the fungi varies between 30 and 110 per cent.

During the next ten years, important results are expected to be achieved through the inoculation of mycorrhizal fungi which can result in cost reduction in terms of fertilisers (amonia, phosphate and triple super phosphate), the expansion of agricultural land by the recovery of deteriorated land and incorporation of low phosphorous, semi-arid and arid lands in forestry and agriculture. It can also result in increase in crop productivity.

The obvious concern that arises is that the increasing uptaking capacity of plant tends to impoverish even more the already poor phosphorous soils of developing countries unless adequate replenishment by industrial super-phosphate is provided. But the developing countries' consumption of industrially-produced phosphorous is already extremely low and the economic possibilities to increase it do not appear very favourable. New biotechnology is expected to provide solutions to this problem through the development of plant varieties which are well-adapted to low phosphorous soils.

Several factors, including poor soils, influence the productivity of crops. In spite of the fact that the world potential area under agriculture appears to be very large (3.7 billion ha), only 10 to 11 per cent of world soils are free from such limiting factors as salinity, alkalinity, drought, water logging, etc.³² Swaminathan noted that in South and South East Asia, about 86.5 million hectares could be made more productive if problems of salinity, alkalinity and other adverse soil conditions were overcome.³³ An alternative or complementary approach to soil recovery focuses on the possibilities to increase plant resistance to certain environmental stresses which could lead to improved agricultural productivity. Resistance to adverse environmental conditions apparently depends on multi-genetic inheritance. It is a fact that some plants show better adaptation or greater resistance to particular soils. Thus, it is obvious that plant crops that can tolerate soil acidity or can adapt to low phosphorous soils are selected where those conditions predominate. Acid soils represent a considerable portion of potential agricultural lands in the tropics. In these areas, cassava is frequently used while rice, maize, sorghum, and sweet potatoes are other varieties which are well adapted to soils characterised by low phosphore. The low phosphorous adaptability of these plants refers to the ability of roots to

absorb phosphore from poor soils and to withstand low phosphorous contents in the plants.

Other factors refer to the adaptability to extreme temperatures and drought resistance. It is reported that cassava and sorghum are among the species more resistant to drought, while rice and field beans are among the more vulnerable. Tissue culture can be used to select particular traits for resistance to specific factors and then transferred to the plants by genetic engineering to the plants.

New biotechnology to overcome biological constraints

Disease, pest and weeds are biological constraints that reduce production and contribute to low productivity in agriculture. The average crop losses resulting from insects, diseases and weeds have been calculated to be as high as 35 per cent of the potential production of all crops, with a higher percentage of 45 per cent for rice and a lower of 24 per cent for wheat. These percentages differ depending on the regions and the cause of loss. The higher losses occur in Asia and Africa, reaching 43.3 and 41.6 per cent respectively of their potential crop value. The lower level corresponds to Europe, with 26 per cent of loss of potential crop value. The major causes are: insect pest, with 11.3 per cent of loss, and the lower, weeds, with 9.7 per cent. These percentages also show variations among regions. So, in Africa, weeds are the main causes of losses: 15.7 per cent of crop value production, while diseases are the main factors in South and North America. Effective pest control practices can reduce up to 50 per cent of the present losses in food production.³⁴

The high-cost modern crop system is largely based on the massive application of toxic chemicals for the control of disease, insects and weeds. The post-war developments witnessed the rise of synthetic organic pesticides, that is, chemicals that are carbon-based compounds, synthesised from petroleum derivatives. At present more than 500 million kgs of pesticides are used worldwide, of which between one-third and one-half are used in the United States alone. In 1976, US\$1.9 billion were spent only in the United States. The pesticides market is dominated in the United States by not more than 12 multinational enterprises (accounting for about US\$7 billion per year, which is indeed only a fraction of the chemical industry). The world pesticide sales rose from US\$8.1 billion in 1972 to US\$12.8 billion in 1983 of which US\$8.5 billion are accounted for by developed countries.

The use of chemical compounds for the control of insect, pests diseases and weeds infestations is one of the major components of the Green Revolution. At present more than 600 pesticides are available on the market. However, the reliance on this single line of crop defense is demonstrated to be self-defeating due to several factors. Among them are: increasing costs related to its energy-intensive character, health hazards, pesticides resistance, the destruction of natural cybernetic mechanisms, the outbreak of secondary pests, and the reduction in pollinators.

On the other hand, pesticides and in particular, herbicides, have been used to replace labour through mechanisation for weeds control, which in developing countries results in a waste of abundant human resources.

Quantitative information on the use of pesticides in developing countries is scarce: yet there is no doubt that in developing countries consumption has increased during the last decade, as is reflected by the fact that in 1983, it represented 15 per cent of the world consumption against 8 per cent in 1972. This figure should be examined in the context of an extremely dynamic market.

For example, between 1972 and 1983, the agricultural consumption of chemical insecticides increased by 58 per cent to reach US\$12.8 billion. Eighty-five per cent of this was concentrated in developed countries.³⁵

In Latin America during the last decade the consumption of pesticides increased at a rate of 8.4 per cent per year, rising from 77 million tonnes of active ingredients to 136 million tonnes. Of this total, 49 per cent is accounted for by insecticides, 27 per cent by herbicides and 24 per cent, by fungicides. The first two expanded at a faster rate: 9.1 per cent and 13.9 per cent respectively.

In developing countries the pesticide consumption is heavily concentrated in cash crops and areas where the Green Revolution has occurred. In West Africa, the use of pesticides for food crops is insignificant. In Latin America, the regional average volume of pesticides applied per hectare is four times greater in cotton plantations than in the case of fruit, coffee, potatoes and sugarcane. During 1974-76, cotton cultivation absorbed 39.6 per cent of the pesticides consumed in Latin America.³⁶ It has been calculated that 70 per cent of the cotton insecticide use is in the developing world³⁷ and that only the cotton production in El Salvador absorbs one fifth of all parathion used in the world.³⁸ In Indonesia, the export crops (coconuts, coffee, sugarcane and rubber) consume 20 times the quantity of pesticides used by farmers that grow food crops for the local market, in spite of the fact that the latter cultivate seven times more acreage than plantation estates.³⁹

Insecticides represent about 90 per cent of the total pesticides used in Africa. The major use of herbicides in Asia, and their growing consumption in Latin America, is explained by the type of cash crops produced. For example, in Malaysia, herbicides are used in two main export-oriented plantations: rubber and oil palm, which cover about 70 per cent of the arable land. The increasing consumption in Latin America is largely explained by the greater acreage allocated to certain crops, particularly soyabeans. During the 1970s, in Latin America the production of soyabeans increased at an annual rate of 25.9 per cent and accounted for 62 per cent of the 15 million extra acreage harvested in the region.⁴⁰ It is important to note that 90 per cent of the world consumption of soyabean pesticides is applied in the United States, which also utilises 60 per cent of the world consumption of maize herbicide.⁴¹

The increase in pesticide application in developing countries has been largely stimulated by governments through different measures, the most frequent of which have been tax exemptions or reduction, low-cost credit, subsidised prices, etc. This is a particularly important aspect since most of the pesticides consumed in the developing countries are imported. The importance of subsidy in the increase of pesticide consumption in developing countries can be illustrated by the case of Indonesia, where the consumption of subsidised pesticides grew from 5,100 tonnes in 1978 to 15,100 tonnes in 1982. The level of subsidy as a percentage of the retail cost is as high as 89 per cent in Senegal, 83 per cent in Egypt, 82 per cent in Indonesia, 87 per cent in Ghana, and 44 per cent in Colombia. These subsidies imply a substantial cost to governments which has been estimated at about US\$200 million in Egypt, about US\$128 million in Indonesia and US\$70 million in Colombia.⁴²

The high cost of pesticides is due to their energy-intensive character and the methods and application practices. Pesticides are carbon-based compounds, synthesised from petroleum derivatives. So the main raw materials for their manufacture are fossil fuels. In addition, the production process requires high inputs of heat and electricity.

Aerial Drift Spray is the main technology used for pesticide application. The inefficiency and wasteful character of this capital-intensive technique is demonstrated by the following data. More than 40 per cent of applied pesticide is normally out of the target area, 15 per cent out of the target crops, 41 per cent out of the target insect and of the 4 per cent near the target insect, 75 per cent is not in contact with it. It is estimated that less than one per cent of the total applied pesticide is absorbed by the insect through contact, inhalation and ingestion.⁴³ Furthermore, it is also reported that only 0.03 per cent of the applied insecticides are absorbed by aphids on bean cultures and 0.02 per cent by mirids on cocoa.⁴⁴ This wasteful use is magnified by the practice followed by farmers who apply pesticides according to the pre-set schedules prepared by sellers and not when needed in response to actual pest threat to a particular crop or ecological area. It is estimated that the actual use of pesticides by the US farmers can be cut by 50 per cent with no effect on crop production if pesticides are applied only when necessary and in relation to specific pests.⁴⁵

Table 9
Losses from pests in the world's major crops

Crop	Losses (percent)			
	Insects	Diseases	Weeds	Total
Rice	26.7	8.9	10.8	46.4
Wheat	5.0	9.1	9.8	23.9
Maize	12.4	9.4	13.0	34.8
Sorghum/Millet	9.6	10.6	17.8	38.0
Potatoes	6.5	21.8	4.0	32.3
Cassava	7.7	16.6	9.2	33.5
Sweet Potatoes	8.9	5.0	11.7	25.5
Tomatoes	7.5	11.6	5.4	24.5
Soyabeans	4.5	11.1	13.5	29.1
Peanuts	17.1	11.5	11.8	40.4
Palm oil	11.6	7.4	9.6	28.6
Copra	14.7	19.3	10.0	44.0
Cottonseed	11.0	9.1	4.5	24.6
Bananas	5.2	23.0	3.0	31.3
Citrus	8.3	9.5	3.8	21.6

Source: Sylvan H. Wittwer: "An assessment of future technological advances in agriculture and their impact on the regulatory environment", in Critical Food Issues of the Eighties edited by M. Chou and D.P. Harmon, Oxford, Pergamon Press, 1979.

Table 10
Pesticide use (excluding herbicides)

Region	Total used US\$ million ^a	US\$/ ha ^b	Total used US\$ million	US\$/ ha ^b	Growth rate in total use (% p.a.)
	1980		2000		1980-2000 ^b
Developing countries:					
Africa	344	3.08	890	5.31	4.9
Far East	725	2.54	1908	5.28	5.0
Latin America	749	6.30	1695	8.78	4.2
Near East	265	4.64	607	8.17	4.2
Total of 90 developing countries	2083	3.63	5100	6.41	4.6
Low income countries	701	2.49	1949	5.38	5.2

^a The report does not indicate to which year the value of the dollar refers. However, it seems likely that the 1980 US\$ is used.

^b Harvested area.

Source: IUCN. Future Hazards from Pesticide Use, Commission on Ecology, Paper No. 6, Gland, 1954.

The situation is even worse in developing countries. For example, only 44 per cent of the applied pesticides by aerial discharge falls into the cotton area of Guatemala's plantations, and the use of parathion in Central America, is 40 times higher than the required amount.⁴⁶

In addition, this waste reinforces the second factor accounting for the inefficiency of this technology, viz. the growing resistance to pesticides. Resistance has been defined as the ability of organisms to evolve strains capable of surviving exposures to dosages to which an earlier generation was vulnerable. Indeed, this genetic resistance results from the biochemical capacity of the pest organisms to convert a pesticide into products that are not toxic to the organism. Other factors that explain this increasing resistance are the ecological characteristics, the frequency and historical pattern of chemical control, etc.

In 1977, FAO reported that the number of pesticides resistant insect species doubled from 182 in 1965 to 364 in 1977. Other authors indicate that 300 insects are resistant to insecticides; 100 biotype diseases are resistant to fungicides and bactericides and 10 weeds to herbicides.⁴² More recently, it has been estimated that between 1970 and 1980, the number of resistant species doubled and that the resistance to certain chemicals has increased as much as 17 fold.

The increasing resistance is associated with the disturbances of the natural cybernetic mechanisms because insecticides are not target specific,

Table 11
Comparison of harvested area for some crops and their share
in the total pesticide, herbicide and insecticide market

Crop	Harvested area (a) (%, 1979)	All pesticides (b) (%)	Herbicides (b) (%)	Insecticides (b) (%)
Cotton	2	14	3.6	10**
Rice	11	10.3	3.7	4.4
Maize	9	15.5	11.3*	3
Soyabean	4	9***	8.3***	1.1
Sorghum	4	1.4 ^c	1. ^c	0.4 ^c
Groundnuts	1.4	1.4 ^c	0.7 ^c	0.4 ^c
Wheat	18	6	4.2	0.6
Subtotal	50%	57%	33%	20%
World total	1 326 320 000.ha (100%)	9.7 billion US\$		

* 60% of the maize herbicide market is in the United States (e).

** 70% of the cotton insecticide usage is in the developing world (e).

*** 90% of the current market is in the United States, mainly herbicides (e).

Sources: IUCN: Future Hazards from Pesticide Use, op. cit.

Table 12
Agricultural crop losses caused by pests in the United States
(US\$ billion)

	Insects (\$) (%)		Diseases (\$) (%)		Weeds (\$) (%)		Total loss (\$) (%)		Potential production (\$)
1974	7.2	13.0	6.6	12	4.4	8.0	18.2	33.0	55
1951-60	3.8	12.9	3.6	12.2	2.5	8.5	9.9	33.6	29.5
1942-51	1.9	7.1	2.8	10.5	3.7	13.8	8.4	31.4	26.7
1910-35	0.6	10.5	NA	NA	NA	NA	NA	NA	5.7
1904	0.4	9.8	NA	NA	NA	NA	NA	NA	4.1

NA = Not available.

Source: Pimente et. al. "Socioeconomic and legal aspects of pest control", in Pest Control Strategies, Academic Press, New York, 1978.

which means that they kill not only the pest organisms but also other species including their predators and parasites. The result is the resurgence of pest and even the outbreak of new secondary pests. Secondary pest outbreaks refer to the development of potentially harmful organisms to a pest character as consequence of the chemical destruction of their predators or their migration. In the case of weeds it has been demonstrated that the chemical destruction of one weed, infestation by chemical compounds leads to replacement by species of weed not vulnerable to the herbicide. For example water hyacinths were replaced by other weeds when treated with chemical herbicides. In Florida (US), it was replaced by alligator weeds and in Sri Lanka by salvinia.

The failure of this chemical approach is reflected by the fact that far from being reduced, crop losses have increased over the last 30 years.

In addition, the health hazards posed by the application of chemical pesticides have been a matter of increasing concern. Data are available on direct human poisoning, but information is scarce on the chronic effects resulting from low level dosage during long term. It has been estimated that in the United States alone, an average of 150 deaths occur per year due to pesticides and more than 100,000 cases per year due to poisoning. The ICAITI reported that between 1972 and 1975 there were more than 14,000 poisoning cases and 40 deaths in the cotton plantations of the Pacific coastal plains of Central America. In the Tiquisate area, in Guatemala, between 30 and 40 people are reported to be treated daily for pesticide poisoning. Finally, WHO statistics indicate that 500,000 people are poisoned by pesticides every year and that at least 5,000 die.

The increasing cost, inefficient application and poor results, the health and environmental hazards and the growing dependence on agro-chemicals suggest that better crop protection can be achieved by integrated pest management, that is, the combination of different available techniques for pest control. In association with long-established farm practices, chemicals and their interaction with a particular crop in a specific environment and scientific understanding of the pest are receiving greater attention. It is in this context that an extremely important contribution to biotechnologies is visualised.

The traditional biological control involves the deliberate introduction of natural enemies in areas where they normally do not live. Biological control has proved to be extremely convenient from the economic point of view. For example, between 1970 and 1973, the biological control of walnut in California, by the introduction of the walnut-aphid obtained from the Islamic Republic of Iran, resulted in economic benefits of the order of US\$ one million per year. In 1976 it was estimated that the economic return resulting from biological control programmes in the United States was equivalent to US\$30 for every US dollar invested.

One problem with biological control is that the identification, research and procedures necessary for the actual implementation is a long-term process - 15 to 20 years are required before the new species can really be introduced. The complementary approach to the traditional biological control is the inundative biological control, which consists of mass release of natural predators during the growing season to attack the pest population immediately. This type of control is done normally in monoculture activities. It has been used largely in China, since it requires large quantities of labour to manipulate the release of predators.

The new biotechnology for crop protection moves along several paths. The causes and characteristics of insect destruction, diseases and weed infestation, call for different methods. Basically, biotechnology developments are oriented towards:

- (i) The production of biopesticides or microbial pesticides;
- (ii) Industrial production of naturally occurring chemicals;
- (iii) Crop cultivars with improved tolerance to herbicides;
- (iv) Development of disease-resistant cultivars; and
- (v) Genetic manipulation of plant and insects.

(i) Production of microbial pesticides

Three types of microbial insecticides are considered: bacterial, viral and fungal. Interest in their development arose from the fact that they are target specific, thus preserving natural predators and beneficial insects (contrary to traditional chemicals). Also the resistance to microbial pesticide seems to be less common. Finally, since they are target specific, they do not affect human beings or animals and they are biodegradable; hence environmentally sound. Bacterial and fungal insecticides are generally produced by fermentation; viral insecticides are produced by infection of insect larvae in insectaries. Micro-organisms have been identified. However, few are produced on a commercial scale since they have to meet several economic and technical conditions. At present, the main problem they have encountered refers to their sensitivity to sunlight, humidity and temperature and their high cost of application.

The best known of microbial pesticides is a bacterial insecticide known as bacillus thuringiensis, marketed as agritrol, biospor, dipel or sporein depending on the manufacturer (Merck, Hoechst, Abbott or Libec). The total market is estimated at about US\$10 million annually. The cost of production is estimated at about US\$8 to 10 per kg of dry weight of cells.⁴⁸ However, its main inconvenience is the cost of application which is estimated at 20-25 per cent higher than the comparable chemical products.⁴⁹ Recently, interest in this bio-insecticide has increased because of the discovery of a particular strain which is very active against mosquitoes larvae that are carrying vectors of malaria.

The production of these microbial insecticides is relatively simple since it uses a traditional fermentation reactor. The process takes about 30 hours after which the product is centrifugated or dried. The product is commercialised either as a liquid or as a powder, or in granular form.

Concerning viral insecticides, only few have been developed commercially. Their advantages are that they are relatively stable on the environment and are compatible with pesticide formulations and application methods currently used. Furthermore, they are particularly virulent only on invertebrates. Hence they are considered safer than other viruses.

Finally, fungal insecticides are in fact not new since they were applied successfully already around 1900 to control the citrus white fly in Florida (US). More than 500 species of fungi are known to be capable of infecting insects. However, a limited number of them are produced commercially. They are boverin produced in the USSR for the control of potato beetle, the AB6-6065 (Abbot) in the United States for the control of citrus rust mite;

biotrol for the control of European corn borer and the metaquino for the control of spittle bug in Brazil sugar cane.

(ii) Production of naturally occurring chemicals

It is known that some plants can produce compounds that are toxic to specific insects, or they release chemicals that adversely affect neighbouring plants therefore acting as herbicides. Biotechnology is oriented towards the identification of genes responsible for this capability and towards cloning and transferring them to non-resistant plant. Activities in this area are not expected to produce new resistant cultivars on a commercial basis in the next 10 to 15 years.

(iii) Crop cultivars with improved tolerance to herbicides

This line of R&D is pursued in the context of the new concept of non-tillage agriculture and crop rotation in order to facilitate the application of chemical herbicides during the growth of one crop without jeopardising the other. One crop can be resistant to a particular herbicide but the following crop in the rotation process may not be. Therefore, the latter cannot be planted on a field treated with such an herbicide. For example, in maize culture, it is common to apply atrazine to control weeds. However, soyabean is very sensitive to atrazine. Thus, soyabean cannot be planted following maize whenever the latter has been treated with atrazine.

The interest of the chemical industry is to produce a soyabean variety resistant to the herbicide produced by the same company in order to capture the market, since the herbicide and the seed of the new variety are to be used together. Similar approaches are pursued in relation to other well-known herbicides like treflan, roundup bromoxynil and so on. The magnitude of these markets is extremely important. For example, the market for a soyabean variety resistant to atrazine has been estimated to be US\$93 million in the United States alone. Unfortunately, this approach is likely to increase the dependence of agriculture on industrial inputs and to increase health and environmental hazards.

(iv) The application of this new biotechnology is examined in the next section.

(v) The genetic manipulation can, in fact, be applied to the previous types of development. It refers to the identification, cloning and transfer of genes in order to increase the virulence of microbial pesticides, to create resistant varieties or to obtain more efficient strains of particular micro-organisms.

Biopesticides production and utilisation in Brazil

In 1984, the gross sales of chemical pesticides in Brazil were more than US\$714 million of which 51 per cent were herbicides, 32.8 per cent, insecticides and 16.1 per cent, fungicides. In relation to volumes, the distribution is different reflecting the different monetary values of the different pesticides.

Between 1964 and 1984, the Brazilian consumption of all types of pesticides increased by 279 per cent. However, this evolution has been different for the three types of pesticides. So, despite the fact that the volume of insecticides used increased by 33 per cent, its share in the total consumption of pesticides decreased from 77 per cent in 1964 to 27-28 per cent in 1984. Herbicides have experienced the most rapid growth. These changes

are clearly related to the transformation of Brazilian agriculture and the expansion of certain specific crops. Soyabean and sugarcane represent 38.2 per cent and 25.6 per cent respectively of the whole consumption of herbicides. Actually, in 1984 the consumption of insecticides and herbicides by these two crops alone represents more than 42 per cent of the value of total pesticide consumption by Brazilian agriculture. The dramatic expansion of soyabean in Brazil, which is now the world's second largest exporter: and an even more impressive expansion of sugarcane production associated with the pro-alcohol programme are well known. Soyabeans production grew from 9,666,000 tonnes in 1974-76 to 15,537,000 tonnes in 1984 while the sugar output increased in the same period from 96,774,000 to 241,518,000 tonnes. With this background Brazilian authorities have initiated activities for the domestic production of microbial pesticides, to complement the already existing domestic industry of agro-chemicals that synthesise about 43 active ingredients of insecticides, herbicides and fungicides and supplies 64, 86 and 68 per cent of the national consumption of insecticides, fungicides and herbicides respectively.

Brazil has two experiences in the production of microbial insecticides and controlling pests that affected two of the most important crops: soyabean and sugarcane. A major Brazilian problem on soyabean plantation has been an insect responsible for as much as 40 per cent of losses due to insects (the *anticarsia gemmatilis* known in Brazil as "largarta de soya"). In 1972, a virus of the baculovirus family was isolated at the Centre Nacional de Pesquisa da Soja (CNPS), laboratory or the governmentally-owned EMBRAPA. In 1933-84, the virus was successfully applied in more than 11,000 hectares of the states of Parana and Rio Grande do Sul. This acreage was increased to 300,000 in 1984-85 and the cost of the protection in soyabean cultures of these states was reduced by 75 per cent in relation to the traditional chemical control.⁵⁰ By 1985, five co-operative schemes were created in Parana, one in Santa Catarina, five in Rio Grande do Sul and one in Sao Paulo, all of them with the institutional and scientific support of EMBRAPA/CNPS for the commercial production of the virus and their diffusion.

The second experience in the production of viral insecticides refers to the control of the "*diatraea saccharalis*", a major problem on the sugarcane plantation. It was estimated that a plague with an average index of infestation of only 2.5 per cent can result in loss of US\$100 per hectare of cultivated sugarcane. In 1978, a particular virus (DsGV) was isolated in the genetic department of the Universidad de Campinas (UNICAMP), near Sao Paulo, and its virulence increased by a factor of 100 through genetic engineering. It has been estimated that the cost of the application will be about US\$10 per hectare. The production is at present in a scaling-up phase.⁵¹

New biotechnology is also applied in Brazil for the production of the fungal insecticides. The studies on these subjects were initiated in 1969 and were concentrated in a particular fungus (the *metharhizium anisopliae*) for controlling a spittle bug (*mahanarva posticata*) known in Brazil as "cigarrinha da folha" that affect sugarcane, soyabean, coffee and pastures. This plague can cause losses of 39 per cent of weight and 34 per cent loss of saccharose content of sugarcane.

The traditional chemical control of the spittle bug proved to be costly and unsuccessful because the agro-toxic killed only a fraction of the adult insect population and a very little fraction of the young population. Even worse, it eliminated the natural predator of the spittle bug. This is why the state-owned Planalsucar initiated the experimental phase with a production of 500 inoculants of fungal insecticides per day which proved to be successful both in pastures and in sugarcane plantations.⁵²

In the first case, its control has a cost of only 18.3 per cent of the traditional control based on chemical pesticides, with an efficiency of 75 per cent. In the case of the sugarcane, the application of the fungal pesticide permitted to eliminate the pest in 1984 at a third of the cost of the chemical content. The major problem faced by the production of fungal pesticide was the lack of technical assistance and marketing problems. This fungal insecticide has also potential application for pest control on coffee plantations, soyabean, orchard, etc.

The problems posed by chemical control in developing countries can be solved by biotechnological developments which are expected to play a major role in the future protection of agricultural crops. In particular, molecular biology should contribute to a better understanding of the mechanisms of pathogeneity, to the early detection of infection, to provide the means for the pest control, and finally (the most ambitious one), to the development of resistant crop varieties.

Another possibility refers to the elimination of disease that affects asexually-propagated crops. The techniques applied in this case are the tissue culture or in-vitro clonal propagation for the production of healthy plants. These are discussed below.

Tissue culture technology

Under the general term of "genetic engineering" different techniques are included: plant cell and tissue culture, gene splicing and recombinant DNA. Discussion is often concentrated on the last two techniques which are indeed more spectacular. However, in the short term, tissue culture is likely to have a greater impact than the other two, because it has a more immediate application in agriculture and secondly because, in many cases, it is a necessary step for more complex and ambitious developments of genetic manipulation.

Tissue culture allows the production of whole plants from single cells. It is indeed a technique used to facilitate the propagation of plant cells and plants. Tissue culture has been applied using shoot tip propagation of ornamental plants that can obtain a high price in the international market. However, it can be applied in developing countries and can result in important short-term developments. In particular, clonal propagation and meristem culture offer the following possibilities:

- rapid multiplication of plant material important for those plants (for example palm oil) whose reproduction takes some time;
- production of disease-free plant material. A particular problem of plant reproduced vegetatively is the problem of diseases. The possibility to select the material to be reproduced and to treat it against diseases and viruses can ensure that cultures entering production are free of bacteria or diseases;
- production of uniform plant material;
- year-round propagation of plant material;
- more rapid development of improved or new varieties;
- better conditions for long-term storage of germplasm and its international exchange.

The present status of tissue culture offers to developing countries interesting possibilities for crop improvement, and for the increase of agricultural acreage through the adequate propagation of healthy plant materials. Tissue culture has been indicated as a labour-intensive process, an aspect extremely interesting from the point of view of developing

countries. Besides, it offers the possibilities to combine the typical agricultural seasonality with the advantages of a year-round production.

Tissue culture techniques appear more mature for plants that are reproduced vegetatively, like potatoes, sugarcane, cassava, oil palm and bananas, all products that play an important role either for food crops or cash crops in developing countries. These techniques have already been applied for two important tropical products: cassava and oil palm tree. Both activities are oriented mainly to the local population. The increasing international demand for oil and fats has stimulated oil production in large plantations, in particular in West Africa and Malaysia. In the case of cassava, the increasing demand for animal feed in European countries has also stimulated the development of plantations for the production of pellets for the European market. Thailand is the main exporter. A more recent interest in cassava arises from its possible use for alcohol and single-cell protein (SCP) production.

The case of cassava

Cassava, also known as manioc, tapioca or yuca, is a tropical root that constitutes a basic food for more than 500 million people around the world. It is cultivated mainly in small holdings throughout the tropics: Asia, Latin America and Africa. In 1984, total world production of cassava was 129 million tonnes, equal in dry matter to about 47 million tonnes of grain. It is ranked as the seventh largest agricultural product in the world, and shows a rate of increase of 2.67 per cent per annum. This increase is largely due to the expansion of production in Asia, that almost doubled between 1972 and 1981 rising from 21.5 million tonnes in 1972 to 40.5 million tonnes in 1981, and 50 million tonnes in 1984 with a rate of increase of 6.6 per cent. Africa is the largest producer with 51 million tonnes and the rate of growth during the ten years considered is 20 per cent. Latin American production is 27 million tonnes and has declined from 31 million tonnes in 1981. At a country level, the largest producer is Brazil, followed by Thailand, India and Nigeria which together represent more than 74 per cent of the world production. Cassava is not cultivated in developed countries. European countries are importing large volumes as animal feed. The leading exporting country is Thailand which represents 85 per cent of the supply to the European market.

Cassava production offers an interesting area for biotechnology application in developing countries along the complete food chain. Biotechnological techniques can be applied in the inoculation of micorrhiza, for the detection of diseases, production of disease-free plant material through in-vitro cloning, for the biological pest control, for the processing of cassava for industrial purposes, and in particular its conversion to alcohol or microbial proteins through SCP systems. Finally, they can be used for the upgrading of traditional food processing based on fermentation like gari and foo-foo.

Scientific and technological development for cassava production is still at an early stage. The traditional process common to other crops for the adoption of technology which originated in industrialised countries does not exist for cassava. Therefore, technologies can be developed from scratch and in accordance with local conditions and requirements. Thus, the agricultural activity in cassava production and processing is free from technological dependence.

Biotechnological application can contribute to the better utilisation of tropical and sub-tropical soils, expanding areas under cultivation, employment possibilities and food production. Its application for the production of

feed-stocks for industrial processes can contribute to an increase in the local availability of energy resources and/or the creation of an export activity that can generate foreign exchange through the production of proteins for animal feed. Finally, the application of biotechnologies for the improvement of traditional fermentation process can contribute to the improvement of the rural diet in developing countries.

In-vitro clonal propagation has been applied to eliminate crops disease in the case of potato and cassava at CIAT in Colombia. In 1972 the frog-skin disease destroyed 7,000 hectares of land cultivated with cassava crops at Quilcacé, Cauca, Colombia. After the disease the production per hectare fell from 15 tonnes to only 0.5 tonnes.⁵³ As a consequence the crop was slowly abandoned and the area cultivated was reduced to only 500 hectares. For lack of raw materials, the plants that treated the roots by fermentation for the production of starch, were forced to close down with their work force migrating to Popayan and Cali. The disease was not known until two years later. In 1974, CIAT described the disease and in the following year it was demonstrated that the frog-skin disease was not due to any nutritional deficiency or toxicity, and that it was not transmitted through the soil. The syndrome was transmitted through infected shoot-tip and tools used to cut infected plants.

In 1978, CIAT initiated research in order to discover the causes of the disease and for the production of clean planting material through in-vitro techniques. In 1980 the causes of the disease were discovered to be associated with a particular virus and a process of disease elimination was initiated.

The typical cassava virus disease, frog-skin disease, common mosaic, Caribbean Mosaic and latent virus were treated by thermotherapy and chemotherapy. Infection with more than one virus can also be eradicated by the production of planting material obtained from shoot-tip culture.

Table 13
Yields of cassava in Colombia after the eradication of
the Caribbean Mosaic through tissue culture and
comparison with an hybrid variety

Clone	Cycle	Fresh Roots (Tonne/ha)	Starch (Tonne/ha)	Shoot-tip No. of plants
Secundina	1st year	25.1	7.1	10
	2nd year	23.0	6.8	10
	3rd year	22.0	5.6	9
	control	8.9	2.1	3
CM.342.170	1st year	34.8	7.9	14
	2nd year	36.2	8.4	10
	3rd year	15.1	3.1	6

Source: W. Roca (1985) "Biotecnologia oportunidades para la investigacion agricola en América Latina, in Fortalecimiento de la Investigacion Agricola en America Latina y el Caribe, CIMMYT, Mexico, 1985.

A hundred per cent cleaning was achieved in cassava stakes infected with frog-skin plus latent virus and frog-skin plus bacterial-blight when they were sprouted at high temperature. High temperature reduces the multiplication of virus.

The propagation of disease-free clones enabled doubling and tripling cassava yields after one year and their stabilisation after three years. For example, the propagation of disease-free clones of a variety called secundina, traditionally affected by Caribbean Mosaic disease, endemic in the North of Colombia, increased from nine tonnes per hectare to 25 tonnes per hectare and the production stabilised after three years, while the yield of hybrid varieties, in spite of higher increase in the first two years, declined in the third one (see Table 14). The yield in fresh weight and starch content increased by 70 per cent.⁵⁴

The application of the in-vitro method to clean cassava infected with frog-skin disease in Quilcace resulted in planting materials that, after one year of distribution to the farmers, show increases from 0.5 tonnes/hectare to 10 tonnes/hectare, recovering from the crisis of 1972 while the acreage dedicated to cassava jumped to 5,000 hectares. Abandoned treatment plants were replaced and production of starch resumed. However, as a consequence of the increased cassava production, its price is now falling.

In-vitro propagation to cassava was also applied to a variety called "Llanera" which, showed continuously declining yields. The study was done in association with another variety, the CMC-40, characterised by its good performance. Thermo-therapy application followed by in-vitro propagation resulted in increased yields of roots and planting material in both varieties, in particular during the first year (see Table 14).

Table 14
Yield increases from in-vitro propagation of cassava

Culture	Parameter	Yield increase (%) over control (a)	
		1st year	2nd year
Llanera	Root-yield - fresh weight	53	25
	- dry weight	22	10
	Planting material(b)	47	46
	Plant height	25	0
	Height first branching	76	26
CMC-40	Root-yield - fresh weight	43	29
	- dry weight	29	2
	Planting material	18	23
	Planting height	6	5
	Height first branching	19	14

a. Conventionally propagated plants, without in-vitro culture.

b. Number of commercial size stakes.

Source: W. Roca, "In vitro clonal propagation to eliminate crop diseases", in Biotechnology in International Agricultural Research, IRRI, 1984.

An interesting aspect of the above cases is that the yield increases were associated with morphological changes in the plants and, in particular, the leaves and the stem, which indicate a more efficient distribution of growth. Apparently, the morphological changes of the leaves were associated with higher photosynthetic efficiency. However, this aspect has not yet been confirmed or evaluated.

The utilisation of in-vitro propagation in other, apparently healthy cassava varieties, resulted in yield increases of 20 to 30 per cent. The dissemination of healthy varieties of cassava prepared at CIAT was implemented through a programme of the Secretaria de Agricultura del Cauca and the Instituto Colombiano Agropecuario, which included control methods for the complete removal of the sources of disease, these being either infected plants or weeds which could host the disease; careful selection of planting material, including quarantine for planting materials from other areas, and finally the careful desinfectation of tools. Control measures were supplemented by training activities and the preparation of information material, including audio-visual aids on the utilisation of the new varieties and the detection of diseases.

The work undertaken in IITA in Nigeria has progressed along similar lines. Improved cassava varieties have been developed and distributed to different African countries. The new varieties are high yielding, resistant to most diseases, bacterial blight and insect pests. They are suitable for human consumption. The IITA programme includes both new seed and tissue culture material.

In Nigeria, more than 80,000 hectares have been planted with new cassava varieties with higher yields ranging from 50 to 300 per cent, more stable production because of greater resistance to pests and diseases, reduced weeding and improved quality. Similar results have been achieved in other countries: In Sierra Leone, the new IITA varieties show higher yields ranging from 9.7 to 25.5 tonnes/hectare, i.e. two to four times the yield of local varieties. In Gabon, in 1982, the new varieties produced high yield ranging from 20 to 40 tonnes/hectare, while in the United Republic of Tanzania, the average yields are 30-35 tonnes/hectare, which compared vary favourably with the 15 tonnes/hectare yield of the local varieties. With the new varieties cloned at IITA, yields ranging from 20 to 50 tonnes/hectare have been achieved in Rwanda, Liberia, Seychelles and Cameroon.

The case of oil palm tree

The high demand for oils and fats has stimulated an increasing demand for palm oil whose production jumped from 1.5 million tonnes in 1960 to 6.8 million tonnes in 1984, while the world vegetable oil production increased from 13.2 to 44.2 million tonnes in the same period. The main producers are Malaysia, with 3.6 million tonnes; Indonesia with 1.0 million tonnes; Nigeria with 750,000 tonnes and Côte d'Ivoire with 145,000 tonnes. Palm oil production is the second largest after soyabean oil. This is a rather recent situation, and is a consequence of steady growth during the last 15 years, at rates higher than other vegetable oils and fats.

Nearly 90 per cent of palm oil is used as edible oils and fats, frying oils and fats, non-dairy creams, margarine, cocoa butter substitutes, bakery and pastry fats. The remaining 10 per cent palm oil used in non-edible product goes for the production of soaps, resins, stearic acids, glycerine, detergents or feedstocks for the petrochemicals industry. The diversity of its uses is undoubtedly one of the reasons for the increasing production and trade. By the middle of the 1980s, the total world exports of palm oil

represented around 25 per cent of the total exports of vegetable oils and fats which fluctuate around 19 million tonnes.

The international market for palm oil is under the control of the largest multinational enterprise of the food sector, Unilever, which indeed controls margarine, oil, detergent and soap markets. The main policy of Unilever has been to acquire the control of the raw materials. Unilever has about 90,000 hectares of plantations in developing countries, two thirds of them dedicated to oil palm trees. In order to face the increasing demand for oils of more than 3 per cent per year for the last two decades Unilever initiated in 1968 the tissue culture technology for the improvement of Malaysian plantations. In 1977 the first clones were planted at Unipamol Kluang. The cloning of palm oil should allow Unilever to overcome the problem of hybridisation and at the same time, the elimination of variability resulting from the sexual reproduction. More uniform plants permit easier harvesting, reaping at the same time, oil of more uniform characteristics and a 30 per cent increase in production in normal average climatic and environmental conditions. This increase in production will more than compensated for the high cost of in-vitro propagation, which has been estimated to be between five and ten times the cost of the seeds.

In 1984, UNIFIELD which is a Unilever joint venture with Harrison and Crosfield, produced 200,000 plantlets in a plant near Bedford in the United Kingdom. A similar unit is planned in Malaysia. The target is the production of 1,000,000 plants per year. However, Unilever ambitions are not limited to the short term. Their research institutes in Netherlands and the United Kingdom are studying the genetic aspects that determine the production of each lipide in the oil. Through molecular genetics the idea is to find out the better varieties by the insertion of genes on plant cells as they are growing on tissue culture. The cross-breed selection at molecular level through the recombinant DNA techniques are the long-term strategy pursued by Unilever to keep control of the world market of detergents and oils. In 1982, Unilever R&D expenditures were estimated at US\$344 million in laboratories in several countries. In the very long term, the countries producing palm oil will face the risk of obtaining it from bacteria, which could eliminate them from the market. Bearing in mind that the international price of palm oil at present is roughly US\$500/tonne which can be kept down thanks to the new clonal varieties, the possibilities of replacement of palm oil by oil obtained through bacterial processes appear remote. At present, it is calculated that one tonne of equivalent palm oil obtained from bacteria could cost around US\$3,000.

In 1984 tissue culture R&D is estimated to have cost Unilever more than US\$2.6 millions. The clones produced are the subject of field trials in Brazil, Colombia, Indonesia, Zaire and Papua New Guinea.

Clonal propagation of oil palm tree has also been undertaken by the French Institut de Recherches pour l'Huile Oleagineuse (IRHO), which in 1976 obtained new plantlets by in vitro culture of leaf tissue of young leaves. The process developed by IRHO and Orstom considers two phases for the micro propagation. The first one involves obtaining a callus and its evolution into embryos; and the second phase is the multiplication and development of the embryos into plantlets which can be transferred to the fields. The complete process lasts around 16 months. The first trials of clones obtained through this process were initiated in 1983 in Côte d'Ivoire. A production of 50,000 in-vitro plants per year was reached in 1984. IRHO and Orstom have signed contracts with the Federal and Land Development Authority (FELDA) of Malaysia and SOCFINDO, a plantation company in Indonesia, for the joint propagation of clones of oil palm trees.

The cloning of oil palm has stimulated research in other tropical trees like coconut tree, a clone of which was obtained by tissue culture at the School of Agriculture and Horticulture of the London University.

The expansion of the Malaysian palm oil plantation has been achieved by the conversion of private rubber plantation to oil palm and by the opening up of new areas under state government land schemes, which in fact adopted the existing system in the rubber sector. In this context, it is a matter of concern that although the oil palm plantation is very labour-intensive, it is less so than rubber plantation. On the other hand, it is argued that the opening of new areas for palm oil plantations has indeed created new sources of employment that more than compensate for the eventual reduction resulting from the conversion of rubber plantations. Moreover, one can also argue that the steady increase in the productivity of palm oil plantations has had favourable impact on incomes and employment.

The biotechnology applications in palm oil is expected to help to overcome biological constraints. The African palm oil appears to be susceptible to South American parasites, thus limiting their expansion. The other objective is the production of a variety more resistant to drought, which is a limiting factor in Africa. Apparently, field trials in Benin, Cameroon, Colombia and Peru have led to positive results.

Palm oil can be used as feedstock for the production of fatty alcohols, glycerine, soap, fatty stearic acids, oleic acids, etc, thus opening up new sources of employment. However, the main concern with rapid propagation of palm oil tree is that it will displace from the market the product of the coconut palm which is grown mainly by small farmers in Kerala (India) and the Philippines. In the case of the Philippines, it is estimated that about 25 per cent of the population depends on coconut palm.

Other applications of tissue culture in developing countries

Coconut trees face problems similar to oil palm trees, e.g. the long time generation of seed propagation and high variation between individual plants. In addition, the different characters of coconut trees manifest themselves after ten years. The cross breeding could therefore take several decades. It is estimated that high-yielding cloned coconut trees can produce five times more production than the traditional trees.

In horticulture, tissue culture has witnessed important developments in several developing countries. This contributes to the diversification of production and introduces possibilities of a new agricultural export activity. In Brazil, the EMBRAPA initiated, at its Centro de Investigaciones de Frutales de Clima Templado, a large programme for the production of fruit typical of temperate areas in order to compete in the international markets. In 1983 the tissue culture of strawberry merrystem reached a production of 20 million plants of six different cultivars (one for industrial process and five for direct consumption). The productivity rose from the Brazilian average of three tonnes per hectare to an average of 12 tonnes per hectare with high maximum values of 22 tonnes per hectare. This production represented 70 per cent of the total Brazilian mechanised plantation of strawberries.⁵⁵ This success has encouraged EMBRAPA to expand its programme so that in 1984, with the same technique, it was possible to produce 10,000 units of mulberry plants which are being distributed to private producers for commercial development.

Another important development concerns potatoes. In Argentina, the micro-propagation of healthy plants enabled the country to become self-sufficient in only five years. In 1980, Argentina imported 41 million tonnes of potato material for seed at a cost of US\$14 million, and in 1985, the import went down to only 1,560 kgs for a total cost of US\$807. In Brazil, EMBRAPA is producing about 40,000 tubers of four different disease-free cultivars of potato. In 1985, it initiated the commercial micro-propagation. Important results have been achieved in ornamental plants in Brazil, Venezuela and other countries.

CHAPTER IV

NEW BIOTECHNOLOGIES FOR FOOD PRODUCTION AND PROCESSING

An important consequence of the development of new biotechnology will be a modification of the agriculture-industry relationships, since the former is the main producer of organic material. The diffusion of bioprocesses can lead to several changes. It may lead to the substitution of existing process and the utilisation of different raw materials for the production of the same or similar goods. It may also open ways for the production of entirely new products.

One of the sectors being increasingly affected is the food and drink industry. The chemical sector can also be affected to the extent that the use of micro-organism activity for the conversion process tends to replace existing chemical processes.

Bioprocess or microbial technology is based on the economic utilisation of four types of micro-organisms: yeasts, moulds, bacteria and actinomycetes. While we know the existence of more than 100,000 micro-organisms, those useful for economic purposes are not more than 100.⁵⁶ The advantages of using micro-organisms derive from their high metabolic rate, their versatility and adaptability. The first refers to the rate of protein production, which is several orders of magnitude higher than the rate of the most efficient crops like soyabeans. In turn, soyabeans are ten times more efficient than cattle in protein production. The importance of this factor is highlighted by the fact that some microorganisms are able to reproduce themselves in only 15 minutes. Adaptability and versatility of microorganisms refer to the possibility of using for their metabolic reaction a wide variety of nutrient sources as raw materials for substrates. This source ranges from hydrocarbons derivatives to agricultural residues and wastes like molasses or cornsteep liquor. It can also include crops specifically grown for this purpose, for example, sugarcane or sugar beat for the production of ethanol and butanol. Other sources are starch crops, wood, straw, husks, sawdust, shells and so on. The products that can be obtained from micro-organisms are of three types, viz. microbial cells, in particular proteins, large molecule in particular enzymes, primary metabolites or metabolic products like aminoacids, and secondary metabolites of which the most representative are the antibiotics.

The food problem and biotechnology for protein production

Cereals are the most important component of human diet which represent more than 60 per cent of the total world food production. Since 1945, world food production and, in particular, cereals production has shown a constant increase with only two exceptional years: 1972 and 1983. In terms of protein and calorie, world food production has always been higher than food requirements.

In 1986 cereal production reached a new record of 1860 million tonnes which means an increase of 2.0 per cent over 1985 and more than 11 per cent over 1983. Nevertheless, between 1980 and 1984 the per capita calorie intake declined in 46 out of 102 developing countries and only 33 of them achieved gains of 0.5 per cent a year or more.⁵⁷ Thus, despite the fact that between 1980 and 1986 food production in developing countries was increasing at a higher annual rate than the world rate (3.5 per cent and 2.5 per cent respectively), the nutritional levels of large Third World populations

suffered declines and the gap between the well-fed and the ill-fed widened.⁵⁸

If the production were divided equally among the world population, each person would receive around 120 g of protein for the wheat eaters and 80 g for the rice eaters, and which in general, represents a global energy intake of about 3,500 calories. Thus, theoretically, the amount of cereals alone would be more than sufficient to feed the present world population. In addition to cereals, other food crops, in particular roots, tubers and pulses also show increases. Among this second group, legumes are specially important, constituting the nutritional basis for several developing countries.

However, cereals are the most important crops at the world level and enjoy some advantages over other crops. They can be easily stored and transported over long distances. In addition, the international trade in cereals is characterised by a relatively well-organised market.

It is clear that cereals alone do not constitute a complete diet and that certain substances should be considered as complements for the achievement of appropriate nutritional levels and health standards. Among these are certain types of aminoacids (in particular methianine and lysine) which are scarcely provided by cereals.

Other food staples like cassava or other roots provide important and even adequate calories. But unfortunately, they have a rather low protein content. Traditionally, people have developed different methods to increase the protein content of their food by mixing or processing them, or for storing perishable products. Consciously or not, micro-organisms have been used for this purpose. The examples can be found in the different soya sauces in China and Japan, obtained by fermentation different types of yogourts widely used in Europe and among pastoralists groups; wines and fermented fruits or typical dishes like ogi, prepared with maize meal, millet or sorghum; gari, obtained by cassava fermentation in Nigeria; tempeh, a very rich protein food of fermented soyabeans which is a basic food in Indonesia; and incaparina, a mixture of maize meal, cotton seeds, etc. normally used in Guatemala. Traditional fermentation processes can be upgraded by the efficient application of scientific knowledge.

However, in addition to these aspects other issues should also be considered. Among the most important is the increasing demand for animal protein. Human beings and livestock are competing for the available supply of cereals and other agricultural crops. Actually, more than 500 million tonnes of world production of cereals (in addition to forage and grass) are used to feed livestock, in particular cattle. Though forage and grass are not suitable for human consumption, very frequently they compete with other food crops for land. Pimentel has calculated that in the US, more than 420 million hectares of land are used to feed cattle.

Pimentel has noted that more than three billion livestock are maintained to supply the animal protein consumed annually in the United States.⁵⁹ The North American livestock is producing around 5.4 million tonnes of animal proteins, which represents a daily supply of 70 g of animal protein. But animals are not direct producers of proteins. What they do is to transform vegetable proteins into animal proteins in a very inefficient way. So, it is estimated that in addition to large amounts of forage and grass, 135 million tonnes of cereals are used to feed livestock in the United States alone.

The efficiency of conversion to animal protein of cattle is of 10 to 15 per cent, implying a loss of 85 to 90 per cent in the conversion process. The pattern of consumption in developed countries shows a tendency to an increased

intake of animal protein which is more than 60 per cent of their average per capita consumption of protein (in North America, it is higher than 70 per cent). In developing countries, animal proteins represent only 21 per cent of the total consumption of protein, which in turn is only 57 per cent of the per capita consumption of protein in developed countries. The problem therefore is not merely to increase food production but rather to increase the protein consumption and to achieve a more balanced diet for the great majority of the world's population.

Averages conceal distributional aspects: it is, therefore, important not only to produce food in adequate quantities and qualities but also to create the conditions for the people to acquire it, that is, to create income and to distribute it adequately.

Three possible strategies (or a combination of them) can be considered for the improvement of protein production and consumption in developing countries, through the utilisation of biotechnologies. The first one to consider is the improvement of existing fermentation processes most frequently used in different regions. The other possibilities are based on the fact that micro-organisms are very effective in protein conversion and that they can grow in different substrates, constituting finally a product in itself (a bacteria, a yeast, a fungi or an algae). Thus, production of microbial protein is the main element of the other two strategies for feeding livestock or as in the third strategy, for direct consumption by human beings.

Obviously, the three possibilities are not mutually exclusive but they constitute an integrated approach to the application of biotechnology, depending on the stage of development of each technology, the local availability of raw materials, substrates, the cultural patterns of each region and the availability of skills and general economic situation.

Improvement of traditional fermentation (food) processes

The basic idea behind this approach is that the efficiency of the process and the nutritional value of traditional food products can be enhanced by the application of scientific knowledge to the upgrading of traditional technologies.

In many cases biotechnologies will make it possible to upgrade traditional technologies in developing countries. In Indonesia the fermentation processes for the preparation of tempeh and tape ketella have been a practice for centuries. This practice has allowed an increase in nutritional value of food which is within the economic possibilities of rural people.⁶⁰ Tempeh not only increases the protein content of the soyabean substrate, but it also introduces vitamin B12 in the final product. In addition, the product requires much less time for cooking - five minutes if deep fat fried or ten minutes if boiled, while the normal cooking time for soyabeans is about six hours.⁶¹

Similarly, through fermentation of the tape ketan the lysine content of rice is increased by 15 per cent and the thiamine content, three times while the protein content of rice is doubled. The tape ketella fermentation permits an increase in the protein content of cassava, between two and four times its original content.

However, the improvement of traditional fermentation procedures requires some basic policies and concrete action. Okafor⁶² noted the following steps to improve traditional fermentation process in Africa:

- determination of the role played by each micro-organism;

- selection and genetic improvement of the essential micro-organisms;
- improvement in the process of fermentation;
- improvement of the raw material used as a substrate for the fermentation process;
- laboratory production;
- pilot plants and scale-up of the laboratory process; and
- industrial production.

What is not mentioned by Okafor however is the fact that the implementation of the above steps presupposes the existence of particular skills. Thus, although fermentation is a well-known process, its improvement requires upgrading of the skills of women who are generally engaged in the process.

These processes for the improvement of traditional technologies should result not only in enhancement of the quality and the nutritive value of the product, but also, in a more efficient process, by shortening the time, they should enable a more efficient use of raw materials. At the same time, a process of upgrading traditional technologies creates a favourable environment for the application of more sophisticated biotechnologies, ending with the utilisation of genetic engineering and complex systems of programming and control based on microelectronics.

Microbial protein production

A more ambitious strategy is the large-scale and maximum production of one microbial protein or a range of different microbial proteins for animal feed and human food. Microbial SCP is the bio-technological process to achieve this objective. SCP is defined as dried cells of micro-organisms such as algae, actinomycetes, bacteria, yeast, moulds and higher fungi, which are grown in large-scale culture systems for use as protein sources in human and animal feeds.⁶³

The process takes advantage of the efficiency of micro-organisms for the production of protein, which is reflected by the fact they can develop between 100 and 1000 times more quickly than a plant or an animal. This advantage is coupled with the fact that these micro-organisms can reach a high degree of protein content - between 40 and 80 per cent on a dry weight base thus constituting a product in themselves. Besides, this product can have a rather well-balanced aminoacid composition. The process of SCP production therefore refers to the large-scale growth of suitable micro-organisms and their subsequent harvesting and processing to a food product.

An advantage of the microbial processes is that quite a large range of raw materials can be considered as substrates for the production of protein, depending on the local availability and on the micro-organisms selected.

On the basis of the above, two different possibilities can be visualised, depending on the final use of the product. The first is the production of food, oriented directly towards the enhancement of human diet. The second possibility is the indirect way of producing SCP for animal feed thus leading to an increased production of animal protein and/or reduction in the demand for expensive proteins like soyabean meal and fish meal for livestock and/or reduction in the livestock competition for agricultural crops and land use.

Another approach which considers the possibilities of the utilisation of different substrates can also be adopted. In this case, the two major alternatives are to produce SCPs on the basis of petrochemical substrates, like gasoil, N-paraffins, methanol, ethanol, etc. The second alternative is to

use readily available waste or agricultural residues, like waste from the starch industry, from the cane or beet sugar industry, mainly bagasse or other cellulosic material like pineapple bagasse, cereal straw, corn stover, or waste effluents like sulphite liquors, whey or molasses. The final possibility is the use of crops intentionally grown for the production of SCP, for example, cassava. At present, apparently very few SCPs have achieved the quality level that satisfies regulations for human consumption. Among them, the one which seems to have achieved this level is mycoprotein.

This second alternative is less capital-intensive than the one based on hydro-carbon, uses renewable and cheaper raw material, is more decentralised, and does not depend on proximity of a petrochemical activity, but rather on agricultural or agro-industrial activities which produce a minimum and regular amount of raw material.

The following are the advantages of SCP production:

- production is relatively free from seasonal variations and from hazards inherent in ecological climate interaction;
- production can be undertaken using a great variety of substrates; thus it can be adapted to the conditions and endowment of resources of different regions;
- short generation time and reproduction rate of microbes (one to two hours) permits a rapid increase of biomass and protein production;
- production of microbes can be enhanced by the selection and genetic manipulation of different strains for the achievement of optimum growth rate and aminoacid compositions.

SCP Production from petrochemical substrate

Production of SCP has been a matter of discussion for at least 40 years. It was stimulated during the 1960s, by the possibilities to use cheap hydrocarbons as a substrate. The artificially low price of oil during the 1950s and 1960s was indeed a driving force towards the production of microbial proteins by the conversion of hydrocarbons which was considered as one solution to the food problem.

In this perspective, in the late 1950s, British Petroleum (BP) initiated the production of microbial protein from petrochemical substrate, obtaining a product that was marketed under the name of "Toprina", which is a yeast grown on a substrate of oil-derived nutrients: parafins or gasoil. The first plant using gas oil was established by BP at Lavera, in France, in a joint venture with the Société Française des Pétroles, for a production of 16,000 tonnes per year. A second process using parafins was developed by British Petroleum at its 4,000 tonnes/year unit in Grangemouth, Scotland. Further in 1975, a joint venture between BP and an Italian Company (ANIC) resulted in Italprotein plant with a capacity of 100,000 tonnes/year with an investment of US\$ 100 million, in Sardinia, Italy. In all these cases, the protein produced is a yeast (*C. Lipolytica*), marketed as Toprina. Toprina has been questioned for human consumption because of its relatively high content of nucleic acid (10 per cent) while plants have between one to two per cent. For this reason, the development of production encountered serious difficulties with the Italian Government which believed that the product was toxic. These problems were aggravated by the increasing cost of oil. The plant is at present practically idle.

However major development in SCP production with "pruteen" has been achieved by the Imperial Chemical Industry (ICI). The ICI process is based on the utilisation of methanol as a substrate, a product which offers some advantages from the engineering point of view, because it is soluble in water,

while methane and parafin are not. The plant built by ICI at a cost of almost US\$100 million came into operation in 1980, and has a capacity of 75,000 tonnes/year. In 1982, the volume of production was 50,000 tonnes. Pruteen is made from a bacteria grown on methanol substrate, oxygen, and nitrogen (supplied as air and ammonia together with inorganic nutrients, like phosphorous calcium, iron, magnesium). The ICI method is a continuous fermentation process which permits higher efficiency of the reactor than the batch process. It also saves on capital and operating costs; but it is a labour-saving process. ICI claims that it is possible to obtain 1,000 million tonnes of "pruteen" over an area of only 100 hectares, while the production of the same amount of protein equivalent of soyabean would require two million hectares.

In the Federal Republic of Germany, Hoechst has developed a similar pruteen product called "probion" with 90 per cent protein isolated, from which much of nucleic acid and other materials, that are considered unsuitable for human consumption, have been removed. The process is using a methanol substrate from which bacteria is grown.

Table 15 summarises some of the main SCP systems based on petrochemical substrate.

SCP production from agro-industrial residues or agricultural crops

The only SCP already approved for human consumption is known as mycoprotein, developed in the United Kingdom by Ranks Hovis McDougall who spent UK£30 million for the production of an isolated fungus, called fusarium. It is grown on a continuous fermentation process using glucose as a substrate, with the addition of other nutrients, and ammonia and ammonium salt as nitrogen sources. However, fusarium grows on a variety of carbohydrate substrates, depending on their local availability, like wheat, starch or cassava. It contains about 46 to 47 per cent of proteins and 14 per cent fat. In addition, it is high in fibrous content which is considered good by nutritionists. It is argued that mycoprotein is quite as nutritious as meat.

All agro-industrial activities leave certain amounts of materials discarded as residues or wastes at each of the different stages of processing. These organic residues and wastes are generally in a solid slurry or liquid form. These materials are not used; normally they are burnt, because their economic value is less than the cost of collection and processing for alternative use.

The most abundant of these residues are cellulosic and starch. About 40 per cent of the earth's organic matter is cellulose, which is indeed the earth's most abundant renewable raw material. Plants are producing about 10 to 15 tonnes of cellulose per person per year.⁶⁴ However the utilisation of cellulose is still facing the problem of fractioning. Cellulose in native state in plant cell walls, occurs as an insoluble complex together with hemi-cellulose and lignin, and requires pre-treatment to disrupt the lignocellulose complex and remove the lignin. There are chemical methods, including hydrolysis using enzymes followed by fermentation in order to separate cellulose from hemicellulose with the recovery of ethanol. Mechanical processing is also possible. Physical methods are based on milling for the separation of lignin. These processes are generally energy intensive and expensive.

Technical developments for the economic use of micro-organisms for the fractioning of cellulose are being pursued and research is being done on the potential use of different alternatives. After treating the cellulosic

Table 15

Single cell protein production from petro-chemical substrates

Producer Company and location	Micro-organism	Substrate	Commercial name of product	Protein content (per cent)	Unit size	Investment	Year	Current produc- tion
British Petroleum Co. (BP) Grange- mouth, Scotland	C. Lipolytica (yeast)	n parafins	Toprina		4,000 t/y			
British Petroleum (BP) and Société Française des Pé- troles, Lavera, France	C. Lipolytica (yeast)	gas oil	Toprina		20,000 t/y		1976	
I.C.I. Billingham, U.K.	M. Methylophilus (bacteria)	Methanol from natural gas	Pruteen	72	76,000 t/y	£40 million	1976 1980	50,000m (1982)
Liquichimica Saline de Monte- Bello, Italy.	(yeasts)	n paraffin			1000,000 t/y			200,000 (1980)
Ital Protein (BP, ANIC), Sarroch, Sardinia, Italy.	C. Lipolytica (yeast)	n paraffin	Torpina		100,000 t/y	US\$ 100m	1975	
Hoechst, A.G. Fed. Rep. Germany	M. Methylophilus (bacteria)	Methanol	Problon	90 per cent				1,000+ (1982)

Source: Compiled by the author from different sources.

material, it can be used together with mineral salts as a substrate for the growing of cells. Such a substrate can be sugarcane bagasse, pineapple bagasse, cereal straws, cornstover, etc. The possibilities of SCP production from cellulosic residues is summarised in Table 16.⁶⁵

Table 16
SCP production from cellulosic wastes with different microbial systems

Micro-organisms	Substrate (pre-treatment)	Substrate Concentration g/l (culture system)	Maximum Protein	Protein Productivity (mg/l-h)
Cellulomonas sp. Alcaligenes Faecalis	Sugar cane bagasse (alkaline)	10 (continuous culture)	3.28	269.0
Cellulomonas sp. Candida utilis	Barley straw (alkaline & wet desint.)	50 (continuous culture)	4.6	550.0
Trichoderma viride and Saccharomyces cerevisiae	Barley straw (alkaline)	40 (batch culture)	4.6	27.4
Chaetomium Cellulolyticum	Corn stover (alkaline)	10 (continuous culture)	-	414.0
Cellulomonas flavigena and xanthomonas sp.	Sugar cane bagasse	(fed batch culture)	20.1	402.0

Source: Mayra de la Torre, SCP from Cellulosic Wastes, in Conservation and Recycling, Vol. 5, No. 1, (1982).

In developing countries the residues from the typical tropical crops, like coffee or pineapple, offers important substrates for the development of SCP. It is calculated that residues from coffee processing represent more than 60 per cent of the weight of fresh fruit of coffee processing through the wet method, which is responsible for at least 50 per cent of the world production of coffee. In the wet method, there are three main residues or by-products: the pulp, representing 40 per cent of the weight of the fresh fruit, the mucilage, amounting to 20 per cent of the weight of the fresh fruit and finally the hulls, accounting for 3.4 per cent. At present, ICAITI (Guatemala) is exploring the utilisation of waste from coffee processing.

Other residues that can be used in developing countries are those originating in the pineapple industry, which are at present dumped into rivers. The magnitude of this potential raw material can be illustrated by the fact that Malaysian pineapple industry is processing yearly 250,000 tonnes of fruits of which only 40,000 tonnes are incorporated in the final product -

210,000 tonnes are discarded as waste. In developed countries, SCP is being obtained from potato waste through the Symba process developed in Sweden.

Traditional tropical crops like cassava may also be a good choice as a substrate for SCP. It has the advantage of being an efficient producer of biomass that can be cultivated in marginal areas. Research activities for the utilisation of cassava for obtaining microbial protein are currently carried out in: France by ORSTOM (Office de la Recherche Scientifique et Technique d'Outre-Mer) and IRCHA (Institut International de la Recherche Chimique Appliquée); Colombia and Canada, in a joint project of CIAT (Centro Internacional de Agricultura Tropical) with the Department of Microbiology of the University of Guelph; and Mexico, at the Centro de Investigacion y Estudios Avanzados (CINVESTAV) of the Instituto Politécnico Nacional (IPN). The CINVESTAV-IPN is considering the possibility of using cassava as a substrate. In this case it is necessary to upgrade the protein content, since cassava roots have normally around one and two per cent content. This means that for obtaining SCP, at present cassava appears as a rather expensive process compared to other processes.

To sum up, SCP production appears as one of the important alternatives for increasing the availability of food, and in particular of protein. At the same time, it reduces pressure over land and competition between crops for animal feed or human consumption. Technically SCP appears as one of the most efficient processes for protein production compared with the traditional processes. For example, 500 kgs of yeast can produce 80 tonnes of protein corresponding to about 50 per cent of the total biomass required in 24 hours, while cattle of the same weight can produce only 400 to 500g of protein during the same time.

SCP production in Mexico and Cuba

A residue with great potentialities for the production of microbial protein in tropical countries is the sugarcane bagasse. Pilot project developments have been undertaken for SCP production at Cinvestav in the Instituto Politécnico Nacional of México.⁶⁶ Obtaining microbial protein from sugarcane bagasse is part of larger attempts to obtain protein from cellulosic waste, including also barley, straw, cornstover, etc., which means that a process for the pre-treatment of lignin should be undertaken before the fermentation process. In the case of Mexico, an alkaline method is adopted. The mixed bacterial culture is then grown on a substrate of detrited bagasse and mineral salts. At the end of the fermentation cycle around 88.5 per cent of the fermented broad is retired, containing about 43.5 g/lit of bacterial cells. The bacterial cell cream is separated from the residual substrate, dried and stored. The efficiency of the recovery is calculated at 98 per cent. The product is commercialised in the form of dry powder. In addition, the biomass suspension that has been separated from the protein cream is flocculated and concentrated by centrifugation, obtaining a dry biomass with 12 to 15 per cent of protein that can be used as forage with the same characteristics of dry alfalfa.⁶⁷

The economic analysis associated with this case requires a total capital investment of around US\$78 million for a plant of 50,000 tonnes capacity per year. The critical point of the process is the pre-treatment with alkali. If the consumption of caustic-soda, which at present represents almost 35 per cent of the cost, can be reduced, the possibilities of the economic process will be enhanced. At the moment Mexican experts are examining the process developed at CENIC in Cuba which is based on the treatment of bagasse in a solid substrate fermentation process. It results in lower chemical and energy requirements, lower capital investment and reduced generation of wastes, with

a higher substrate fraction available for micro-organisms. If the process is made economically feasible, then the alkali consumption can be reduced between 50 and 80 per cent with the consequent reduction of costs, without considering the possibilities of further economic advantages resulting from the lower consumption of chemicals and steam.

Another possibility envisaged for the reduction of the investment and overall costs is the shortening of doubling time of the biomass. The CINVESTAV project assessment was done on the basis of a doubling time of 5.8 hours. However, the laboratory studies at the IPN indicate that it is possible to achieve a doubling time of 4.5 which can result in capital reduction of about 10 per cent. Therefore, the experts of the CINVESTAV-IPN conclude that a reduction of about 60 per cent in alkali consumption and 10 per cent in capital investment are possible. Therefore, the SCP protein can be marketed at a price lower than US\$1,000 per tonne. Further economic reduction can be achieved if the hemicellulose and lignin can be recovered.

In Cuba, important developments have been made to utilise molasses for the production of proteins by using the waste from distilleries. The development of microbial proteins was stimulated by the existence of large quantities of cane molasses and the need to reduce imports of cereals for animal protein production. The Cuban production of microbial protein is an interesting case because it illustrates some of the problems that developing countries are facing in the transfer of technology from the advanced countries. The first fermentation plant was ordered from a French firm, which provided a plant design for temperate weather. Therefore, it was unable to operate large quantities of fermentation without additional cooling systems. Instead of exploring a more appropriate design for the local conditions, the French company decided to withdraw and to pay the fine stipulated in the contract for not fulfilling the conditions. The Instituto Cubano de Investigaciones sobre los Derivados de la Caña de Azúcar decided to redesign the plant, in accordance with Cuban conditions. Before the initiation of production of microbial proteins at the factory of Ciro Redondo, the same Institute also solved other problems confronted. Since then around 10 plants have been built. The production of these plants is oriented to animal feed, in particular pork and beef production.⁶⁸

Recovery of microbial protein from molasses generated by the cane industry is also pursued at CINVESTAV-IPN in Mexico. In 1984, the Mexican production of molasses was of 1,234,000 tonnes, of which around 188,000 tonnes were exported. However, since the molasses prices are relatively low, the possibility of upgrading it for SCP has been considered appropriate.

The process adopted in Mexico for the processing of SCP from molasses is based on the plants already operating in Cuba, where the molasses are pre-treated in order to eliminate impurities and subsequent sterilisation for the fermentation process.

Enzyme engineering

Another important use of micro-organisms in food processing refers to the production and utilisation of large molecules, like isolated enzymes and plant, animal or bacterial systems as catalysts in biological transformation processes. The most important products of these micro-organisms are the enzymes. Enzyme technology is concerned with the production, purification and immobilisation of enzymes and their subsequent application in industry and in medicine, chemistry and research.

Even though enzymes have been used as catalyst since antiquity their major development began only in 1930. Despite the fact that around 3,000 enzymes have been identified and 200 have been studied, no more than 20 have been used on an industrial scale.

Traditionally, enzymes were obtained from vegetables and animals as a by-product of slaughter houses. These developments make the microbial production of enzymes more attractive than the traditional ones, which present several limitations. For example, enzymes from animals depend on the slaughtering of animals and, therefore, on their availability, and the fluctuations of meat market. On the other hand, enzymes from plants are frequently contaminated; and in both cases, the supply has a seasonal character.

Today microbial production of enzymes by fermentation using fungi, bacteria or yeasts has largely replaced the plant and animal enzymes. Microbial production of enzymes is not seasonal since it is obtained in artificial sterilised cultures, and since it is produced not as a by-product, it does not depend on the vagaries of the main product.

However, one of the inconveniences of enzymes is their instability in losing their activity in conditions of elevated temperatures and/or acidity. This is the reason why, until recently, enzymes were of limited use. They were not recovered from the final product. Thus their use was relatively costly. This situation has changed dramatically during the last few years, thanks to some technological breakthroughs which enable to immobilise enzymes in a solid surface, which permits their recuperation after use.

The new enzyme technology has several economic advantages (in addition to those already mentioned) viz. the cost of catalyst is dramatically reduced since it is not lost in the process, continuous process is made possible, the size and cost of the reactor is reduced, and so is waste generation. It has negative employment implications however since it tends to reduce labour requirements in the continuous processes and indirectly, in the plant and animal enzyme recovery. It is estimated that the immobilisation technique can result in a reduction of capital investment by as much as 33 per cent through the replacement of conventional batch plants by continuous plants.

The world production of enzymes is under the control of few multinationals, three of which control 80 per cent of the global market, and two: Gist Brocades of the Netherlands and Novo of Denmark, together more than 60 per cent of the world market, which is estimated at over 50,000 tonnes.

The applications of enzymes are quite large, although, at present they are concentrated in industry and in particular brewing and wine-making, sugar, flavouring, dairy, leather, waste treatment, textiles and chemicals, paper-making and alcohol. The other applications of enzymes are in therapy, anti-tumor treatment, anti-inflammatory, diagnostic, cosmetics and genetic engineering.

Isoglucose or High Fructose Corn Syrup (HFCS)

From an economic point of view, the major impact of immoviles (isolated enzymes) has been, in the sugar sector and in particular for the production of high fructose corn syrup (HFCS) or isoglucose which is the first and most important large-scale industrial application of immobilised enzymes. In only ten years isoglucose acquired the control of 10 per cent of calorific sweeteners in the United States. At present isoglucose controls 28 per cent of the North American sweeteners' market and 45 per cent of the total

industrial sugar market. In Japan, isoglucose covers 10 per cent of the sugar demand.

Isoglucose is a sweetener which competes with the natural substitutes obtained from corn and sugar. In particular, it meets the requirements of the industrial sector, which uses it in liquid form, since up to now it has not been possible to obtain it economically in crystallised form.

The isoglucose permits a better conservation of food through slower development of bacteria, without the need for additives. At the same time, it lowers the freezing point, which makes it very attractive for ice-cream preparation. Another interesting aspect of isoglucose is that it has a synergic effect of sweetness, that is, equal percentage of isoglucose and sucrose produce a higher sweetness than the addition of the sweetness of both.

At present, isoglucose is limited to industrial use in local markets due to its high cost and difficult transport. (It is produced only in liquid form.) Therefore, it is a solution for those countries that are either net importers of sugar or which account for a significant production of corn. The United States produces 46 per cent of the world production of corn, exporting 30 per cent and with a regular surplus of corn. At the same time, it is a net importer of sugar.

Corn represents 50 per cent of the cost of isoglucose; energy 20 per cent and between 10 and 43 per cent is the labour cost and only 5 per cent is the cost of of enzymes. The tendency is for a further reduction of enzymes and of labour cost, which is associated with an increasing capital-intensive character of production, similar to the chemical industry, and favoured by the continuing process, typical of liquid feeding lines of the production unit. Furthermore, there is a tendency for automation to increase with continuous flow processes. On this basis, it is expected that isoglucose will substitute up to 90 per cent of sugar in the beverage sector, 60 per cent in canning, 40 per cent in processed food, 30 per cent in dairy production and 25 per cent in baking. This rate of substitution is important since liquid sugar accounted for 57 per cent of the total sugar use in the United States. The main consequence of the development of isoglucose has been the reduction of sugar imports from developing countries (See Table 17). The main developing countries which have been affected by this are: the Dominican Republic, with a reduction of 39 per cent, El Salvador 72 per cent, Nicaragua 46 per cent and Argentina and Brazil 34 and 35 per cent respectively.

Table 17
US raw sugar imports by countries/regions of origin
(Percentages)

	<u>1976</u>	<u>1980</u>
Caribbean Islands	26	19
Central America	18	16
South America	12	33
Philippines	20	9
Others	24	24

Source: R. Crott, "The impact of Isoglucose on the International Sugar Market", in S. Jacobsson et al., The Biotechnological Challenge, London, Cambridge University Press, 1986.

Crott indicated that the American market absorbed 80 per cent of all the sugar exports of the Dominican Republic, which represents 25 to 40 per cent of total export revenues, or about 60 per cent of foreign exchange earnings of the country. The development of isoglucose in Canada has affected mainly Australia, South Africa and Cuba, which account for almost 90 per cent of all raw sugar imported by Canada. In this case, the most affected countries have been the marginal suppliers, those responsible for the remaining 10 to 20 per cent, viz. Jamaica, Guayana, Fiji, Thailand and Mauritius.

Biotechnologies and amino-acids production

The most important primary metabolites in the fermentation industry are the aminoacids which are small molecules that are assembled to make up proteins. Some of them, like lysine and methionine, are very important from the nutritional point of view.

The importance of these aminoacids is highlighted by the fact that cereals are in general deficient in lysine and methionine, while high-grade proteins, like meat, fish or soya are also poor in sulphur aminoacids, particularly methionine. Since lysine and methionine are the limiting aminoacids, their production at industrial scale appears attractive for the improvement of human diet.

The commercial production of aminoacids is not limited to food additives. The main uses of aminoacids are the following: improvement of the quality and flavour of food [important aminoacids for this are the glutamic acid, commercially known as monosodium glutamate (MSG)]; a second use in the food industry is as a supplement in order to upgrade the nutritional value of food, for example, methionine is used to enrich soyabean meal, while lysine and tryptophan are used for the enrichment of other vegetable proteins. Besides their use in the food industry, aminoacids are very important in the chemical and pharmaceutical industry, either for the manufacture of detergents and agricultural chemicals or for therapeutical uses or psychotherapeutical agents.

According to the US Office of Technology Assessment (OTA), in 1982 the worldwide sales volumes of aminoacids were 445,000 tonnes, valued at US\$1,15 billion with an estimated growth rate of 7 to 10 per cent per year.⁶⁹ Their use in food production and animal feed represents 66 per cent of the volume and 52 per cent of the value, while the second use, animal feed, represents 33 per cent of the volume and 30 per cent of the value. The above figures reveal that the third use of aminoacids, which is basically the pharmaceutical one, representing only 1 per cent of the volume, is however responsible for 18 per cent of the value and is precisely the sector which is expanding more rapidly in developed countries. This trend confirms that technology develops more rapidly in those product sectors which have higher aggregate value.

The most important aminoacids in the food industry are the glutamatic acid, lysine, methionine, tryptophane, aspartic acid and phenylalanine. The last two have faced problems of cost which have been overcome with the use of immobilised enzymes which helped reduce the cost of production by 40 per cent. Recently aspartic acid produced by fermentation has become available in the market. Of the other aminoacids, methionine is produced by chemical synthesis (the Monsanto process) which permits its recovery at extremely low prices. However, for the other aminoacids, fermentation processes are more efficient and this is due to a metabolic characteristic of most aminoacids.

The most important production of aminoacids by fermentation is glutamic acid, commercially presented as sodium salt of glutamic acid under the name of monosodium glutamate (MSG) used as food additive. The actual production of MSG is estimated at about 400,000 t/year, of which 10 per cent are consumed in the United States, which needs to import 50 per cent of its requirements.

The second most important aminoacid produced by fermentation is lysine, reaching 40,000 t/year for a value of US\$160 million to US\$200 million. The world production of lysine is controlled by the Japanese industry. More recently EUROLYSINE of France, MIWON of the Republic of Korea and FERMEX of Mexico have taken advantage of the high market demand thus competing with the Japanese companies. The most important market for lysine is the United States, with about 20,000 tonnes. This has led the Japanese companies to build two plants in the United States. One in Cape Girardeau, Missouri, for a capacity of 15,000 tonnes/year and the second one in Eddyville in Iowa, for a capacity of 6,000 t/year. Lysine is competing with soyabean meal. Therefore, it is highly dependent on the fluctuation of soyabean meal prices. In 1985, soyabean meal processes were, at their lowest prices which means that in order to be competitive, lysine from fermentation processes should be very efficient. At present, in the US, the strain of micro-organisms used yields of 50g of lysine per litre of fermentation broth. So corn syrup of the American plants cannot compete with the production of lysine from Japan or the Republic of Korea, nor with soyabeans meals, at its current prices. However, either with the use of genetic engineering micro-organisms or through the construction of aminoacids multipurpose plants, lysine obtained through fermentation processes can be competitive in the market. The first alternative is oriented towards obtaining a yield of 100 to 240g of lysine per litre, which would permit the recovery of lysine marketable at US\$ 1.15 per pound. With this price it is expected that the market can expand from the present level of 40,000 tonnes to 140,000 tonnes per year.

Another alternative is the construction of a multi-purpose plant for the production of lysine and tryptophan, which would reduce the cost of the initial investment and permit the production of both aminoacids at competitive prices as indicated in Table 18.

Table 18
Investment in lysine and tryptophan aminoacids

Plant	Single purpose plants		Multi-purpose plants	
Product	L-lysine. HCI	L-tryptophan	L-lysine. HCI & L-tryptophan	
Yearly volume	12,000 metric tonnes	4,000 metric tonnes	6,870 metric tonnes	1,670 metric tonnes
Initial Investment	\$ 50 million	\$ 56 million	\$ 56 million	
Payout Period	9 years	2.3 years	4 years	
Product selling price	\$1.70/lb	\$10.00/lb	\$1.40/lb	\$10.00/lb

Source: ELDIB Engineering & Research, Inc. Andrew Eldib et al (Biotechnology, 1985).

CHAPTER V

CONCLUSIONS

For developing countries new emerging technologies, and biotechnology in particular, imply a strategic alternative towards a more self-reliant and sustainable pattern of development. The developments in biotechnology are taking place simultaneously with other science-based technological innovations, mainly informatics but also new materials, which are likely to greatly affect the form and the speed of diffusion of new biotechnology. The combination of very pervasive new biotechnology with even more pervasive information technology is likely to magnify the impact of the former in both developed and developing countries.

The impact of new biotechnology cannot be extrapolated from historical experiences. Moreover, new biotechnology can be used for different purposes, and a conflict of interest between developed and developing countries is very likely to arise. In developed countries, the basic problem is the increasing surplus, particularly of cereals (wheat, maize), sugar and dairy products. In contrast, despite impressive increases in productivity and production, some developing countries are facing dramatic shortages of food and agricultural raw materials. And indeed the nutritional gap has increased between well-fed and ill-fed countries. So the number of undernourished is still around 500 million people who cannot afford to buy enough food for the satisfaction of the minimum dietary requirements. The productivity gap in agriculture in the two groups of countries is far from narrowing. The existing surplus in developed countries reduces the international market for some products of developing countries, such as sugar and meat. New biotechnology enables developed countries to put existing surplus to alternative uses. A classic example is the application of the enzyme immobilisation technique for the conversion of starch and the production of HFCS (Isoglucose) that replaced glucose from sugarcane in the food industry.

New biotechnology will also reduce the dependence of the developed countries on imported vegetable proteins and other more specific products like medicinal castor oil, citronella, palm oil or cocoa butter. SCP from fossil fuel or from agro-industrial residues like cellulose, molasses, pulp and paper effluent or whey from dairy industries, are likely to displace the soya meal protein produced in Argentina and Brazil, the cassava pellets produced in the Philippines or the peanut oils from western Africa.

There is no doubt that the economies of several Third World countries would be seriously affected if the EEC member states decided to become self-sufficient in oil-based products. Probably the most publicised example of negative impact of biotechnology on developing countries is the case of high fructose syrup (HFCS) which is regarded as one of the main causes of the crisis of the sugar market during the 1980s with a continuous decline in the price of raw sugar from 62.3 US cents in 1980 to less than 12 cents per pound in 1986.

Concern has been expressed about biotechnology impacts on the international trade of products exported by developing countries and on employment. Biotechnology is producing economic changes at two levels to the extent that: first introduces new processes that permit a more standardised and larger production of some already existing products, thus facilitating their popularisation. Secondly, biotechnology introduces new products which

are in fact direct substitutes of those existing in the market. Examples of the first are the fermentation process enhanced by enzymatic engineering and genetic manipulation that enable replacement of chemical processes that are more energy intensive, more expensive and more pollutant, or to enhance the performance of fermentation-based industrial activities. A clear example of this is the ethanol produced by fermentation (a case that is not analysed in this paper). Successive improvement of the fermentation technology has led to the replacement of synthetic ethanol by fermentation-produced ethanol. The latter was not used for industrial purposes.

The second situation is illustrated by the production, through bioprocesses, of new products that replace (or have the potentialities to replace) existing ones. Example of the first is the case of HFCS that replaced the liquid sucrose/glucose syrup in food and beverage sectors. SCP is an example of a potential substitute (although Cuba has already used it) for animal feed protein.

The important element to bear in mind is that the diffusion of biotechnology has been and will be largely determined not only by the technical aspects but rather by economic factors and political decisions.

Moreover, biotechnologies are blurring sectoral boundaries by linking apparently totally different products, through price fluctuations in the international markets. Actually the diffusion of HFCS and SCP has been governed by the changes in the price relationship between apparently non-linked feedstocks and commodities: oil, sugar, maize, molasses, soyabean meal and so on. Therefore unexpected changes in the international market may well deter or postpone the diffusion of biotechnological innovations, particularly when international price fluctuations affect raw materials. The case in point is the one concerning SCP. We have noted (Chapter 4) that the low price of oil during the 1960s stimulated the development of SCP protein on the basis of methanol and paraffine as substrate (the ICI and ANIC BP processes). Huge investments were made but the energy crisis of the 1970s kept idle or at least largely unused the plants in UK and Italy. This situation was accelerated by the persistent decline in the price of soyabean meal caused mainly by Brazil's entry into the Market, which was favoured by another bioprocess: the large-scale production of Rhizobium inoculant, which avoided the use of synthetic fertiliser.

The second element that permits biotechnology diffusion is the availability of large and regular supply of substrate for fermentation at low prices. For example, the production of HFCS in the United States was made possible because of the large surplus of maize to be used as feedstock and its declining price.

Similarly, the Cuban production of SCP protein was made possible by the regular supply of a byproduct of high protein content, molasses, with a very low opportunity cost, that can be used as a cheap raw material in a process in which the incidence of raw material cost is important (around 60 per cent as we noted in Chapter 4). Actually the cost of production of molasses is almost nil. Moreover, the declining price of sugar in international markets contributed to keeping the opportunity cost of the byproduct at a very low level, thus stimulating its use.

A similar situation is presented by corn for HFCS. Actually the production of byproducts of the wet-milling process is reflected in the cost of production of corn. The main byproducts are starch, maize oil and gluten for animal feed. Starch can be used for the production of HFCS or ethanol. Its use in one or the other process is determined by economic and political

decisions, which in the United States favoured its use for HFCS in order to reduce large corn surplus, replace imported sucrose, and alleviate the growing trade deficit.

This last point brings us to a third important element that permitted rapid diffusion of biotechnology in the HFCS case, that is, the governmental policy. In the United States, the production of HFCS benefits from a price support programme for domestically-produced sugar with a guaranteed internal price.

So biotechnology diffusion depends not only on the new technology per se, but on a combination of several economic and political factors. The main factors can be summarised as:

- (a) the regular availability of large amounts of feedstocks at low prices (or the possibilities to produce them);
- (b) the opportunity cost of the feedstock;
- (c) the price of alternative feedstocks (e.g. oil versus molasses for SCP production);
- (d) the price of the final product and of its substitute (e.g. SCP and fish meal or soyabean meal protein; HFCS and sucrose);
- (e) economic and political factors (e.g. United States balance of payments and interest to eliminate sucrose imports; Cuba is interested in substituting imported protein for animal feed);
- (f) other factors may also favour the diffusion of biotechnology. The case in point is the HFCS in Japan (the second largest producer of HFCS after the United States). The adoption of HFCS has largely been the result of a different tax treatment of sugar and corn, both of which are imported. However, while corn is not subject to import duties and taxes, sugar is. This purely economic fact together with the Japanese high level of mastery on enzymatic technology prompted the substitution.

To sum up, the displacement of traditional developing countries export products does not result exclusively from the biotechnology innovation per se. Rather it would depend on how far the new technological innovation corresponds to the economic or political objectives, and on the measures adopted by governments in order to make feasible the large-scale application of the new technology.

On the other hand, Third World countries should be able to create employment and incomes by using new biotechnology to increase biomass production and use it efficiently, to reduce biological or ecological constraints, to diversify the spectrum of their agricultural products, to improve the efficiency in food processing and conservation, to reduce dependence on imported industrial products, to reduce the cost of agricultural activities, to improve the nutritional content of products and locally-processed food, to develop new varieties suited to local conditions and to shorten the reproduction cycle of tropical species, etc. For example, a disease-resistant plant eliminates the need for chemical pesticides, and microbial pesticides reduce or even eliminate the need for chemical products.

In Cuba, SCP has totally replaced the import of protein for cattle feed. It creates a new sort of employment and increases the value of sugarcane plantations since molasses are used as substrate. However, the creation of employment by plant activities is relatively low. In the case of Cuba, it is slightly more than 100 persons. But the indirect employment effects can be important, e.g. through the use of additional land and the release of foreign exchange through discontinuation of imports of animal feed.

One of the case studies mentioned in Chapter 3 refers to the increasing application of rhizobium inoculants for synthetic fertilisers in soyabean production in Brazil. The direct employment effect, on which we do not have data, can be important since the soya expansion in Brazil in the last ten years was undertaken to open the agricultural frontier. The production of rhizobium has a positive impact on rural employment and incomes, and it can help save foreign exchange currently spent on imported fertilisers. Similar considerations are valid for the production and diffusion of microbial pesticides.

Tissue culture application in developing countries is also likely to create new employment and to favour sustainable and more self-reliant rural development. We have mentioned the application of tissue culture for the development of disease-free cultivars of cassava and the dramatic recovery of agricultural areas affected by diseases. Argentina has eliminated the import of potato seed which is now produced by tissue culture and Brazil has expanded the production of strawberries. In all these cases, the new biotechnology created relatively little employment in the tissue culture production itself but resulted in important indirect effects either by the expansion of agricultural areas or the incorporation of new crops into the commercial activities of the country concerned.

In food processing, the application of biotechnology is not likely to have important direct employment effects. Normally, fermentation activities absorb little skilled labour. Furthermore, the tendency is towards continuous processing which has the advantage of raising productivity but a disadvantage of reducing demand for labour. The direct employment impact is likely to be further reduced if automation is applied. For example, the production of glucose isomerase is computer controlled. Therefore, the most important impact is indirect, mainly accruing from the production, pre-processing and transport of the raw material. For example, for SCP the major component of the cost is molasses or bagasse and in the case of HFCS, it is maize. In both cases the organic substrate represents over 50 per cent of the cost of production.

Qualitatively, in developing countries the applications of new biotechnology in agriculture and food processing are likely to result in demand for more skilled labour. It also calls for a more flexible occupational structure.

The production of inoculants requires local capabilities for the identification of the most appropriate rhizobium strain and its isolation and reproduction. Besides, during the manipulation of the inoculants, certain skills would be needed to preserve the effectiveness of the inoculant and to coat it appropriately with the seed. The tissue culture process, too, requires skilled persons, both at the laboratory stage and at the field.

The shortage of skilled manpower in biotechnology is a matter of concern not only to developing countries but also to developed countries. This shortage will become more serious in the long term, as genetic engineering requires very specific and skilled professionals. This is why it is of vital importance to consider simultaneously the present demand for skilled labour and the future demand which is likely to be different.

At present, developing countries are no doubt short of manpower to deal with biotechnology, particularly at the lowest echelons, that is, production operatives or technicians in different phases of biotechnological processes. The situation is aggravated as a result of the brain-drain (i.e. migration of skilled foreign personnel) notably to developed countries.

As a science-based innovation, biotechnology requires a new attitude to technology. This means that the complete educational system should be re-examined and adapted in order to supply highly-qualified people for developing, designing, producing, using and maintaining equipment and processes associated with new biotechnology.

One of the most important consequences of technological innovations that took place in agriculture over the last 50 years is the increasing dependence of agriculture on inputs supplied by the industrial sector. The growing importance of agro-industry also makes agriculture dependent on the industries that process agricultural products. Technological innovation associated with multinational agro-business has created additional intermediaries between the agricultural producer and the final consumer. New biotechnology may be able to reduce the dependence of developing countries on the industrial countries through the local production of rhizobium inoculants or bio-pesticides. A variety of seeds capable of fixing nitrogen reduces or eliminates the need for chemical fertilisers. However, this potential of biotechnology is threatening the position of multinational chemical input suppliers who are interested in controlling the new technology. Biotechnology can be used to reduce agriculture's dependence on chemical inputs but it can also be applied to increase dependence as is illustrated by the development of plant varieties resistant to herbicide atrazine and round-up.

New biotechnology is said to be scale-neutral. It favours traditional farming systems based on mixed crops or inter-cropping. However, the neutrality was also considered to be a feature of high-yielding varieties (HYVs) of the Green Revolution, and yet they have caused land concentration, further mechanisation and labour displacement. It follows that if the increases in production and productivity are to be coupled with other objectives related to employment, income and land ownership, the strategies and measures concerning biotechnologies should be integrated into a global policy covering all these aspects.

The existing views are split regarding the employment and income implications of new biotechnology. Some people claim that the diffusion of new biotechnology will displace labour and reduce income opportunities, depressing the already depressed rural areas of the Third World. On the other extreme are those who believe that the new biotechnologies will create new activities and therefore new jobs and sources of income. The advocates of this position go further by arguing that biotechnology diffusion will require specific services and infrastructure which would have a favourable multiplier effect on the overall development in the Third World.

An important question is the time horizon of the impacts of the new biotechnological developments. In previous paragraphs we show that their diffusion is governed to a great extent by economic and political decisions tailored to serve specific purposes. On the other hand, in Chapters III and IV we noted that several new biotechnological innovations are not likely to make an early entry in the productive process. Furthermore, since diffusion is a rather slow process the social impact will manifest itself after a rather long period. For example, tissue culture in tropical plants like palm oil or coconut is not likely to yield impacts in the near future. Even assuming that the existing efforts by Unilever and France on palm oil are successful, it will still be necessary for the plant to be planted and for it to grow until its productive age. This means that oil production will not be achieved at least during the next 10 years. We also observed that application of genetic engineering in the seed industry and nitrogenous fixation are not likely to achieve concrete results in the foreseeable future.

Therefore, in the short term, the main impact on the agricultural sector will come from the diffusion and enhancement of technology already applied, e.g. Rhizobium inoculant, and tissue culture in some plants like tubers and roots, (e.g. cassava and potato), or simple plants (e.g. strawberries and ornamental plants). In all these cases, developing countries are likely to benefit from the new innovation provided that appropriate government policies are adopted, people are trained and mechanisms for the diffusion of technologies are introduced.

A more complex situation seems to be the one on pesticides. In this case the interest of developing countries is in conflict with that of the multinationals which are active in the chemical sectors and are making efforts to secure markets. The Brazilian experience shows that biopesticides developments can be quite rapid, with favourable effects on the domestic agricultural sector.

The importance of the multinationals in biotechnology diffusion is also great in the food-processing sector. Evaluating the future impacts of biotechnology is very difficult for several reasons. The biotechnological innovations are taking place within an oligopolistic framework which maintains secrecy concerning their stage of development and characteristics. We have seen that the above situation is particularly evident in the enzymatic industry which is concentrated (more than 60 per cent) in only two multinationals, viz. Novo industries and Gist Brocades. Similar situation exists regarding the production of amino acids through fermentation. The production is dominated by three Japanese companies: Ajinomoto, Kyowahakko and Mitsui.

To sum up, biotechnology innovation and diffusion is an irreversible scientifically-based technological process. It can have negative or positive effects on the economies of developing countries, depending upon the economic and institutional mechanisms that each country will adopt for the application of these innovations.

At the international level, developed countries and multinational enterprises are making effort to apply biotechnology to solve their particular problems (agricultural surplus and dependence on imported raw materials) or to secure markets for their production (chemical sector). This is a fact that developing countries have to face.

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