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Socio Economic Aspects of Technological Innovation in Food Production Systems (**)

« Indeed, it is a strange-disposed time:
But men may construe things, after their fashion,
Clean from the purpose of the things themselves ».
WILLIAM SHAKESPEARE: *Julius Caesar*.

1. Famine and Malnutrition in the Midst of Plenty

In 1985, the world production of cereals, which is considered the main indicator of the food situation, reached a peak of 1,831 million tons, or about 36 million tons more than in 1984, since stocks also raised the estimated food supply of cereals for the period 1985/86 at a record level of 1,989 million tons, that is 4% more than in the previous period. The production of other food staples: roots and tubers, pulses, oils and fats also shows increasing trends, though not so regular and steady as in the case of cereals.

The utilization of cereals for the period 1985/86 is estimated at 1,620 million tons, exceeding by about 20 million tons the figure of 1984/85 (1,603 million tons). This lesser utilization of cereals is expected to result in a new record of stocks of about 370 million tons for the season 1985/86 [1].

During the post World War II period, food production increased constantly. Between 1970 and 1976 the world food production increased at an annual rate of 2.4 percent and the 1984 production was almost 25% higher than in 1974. The growth in relative terms has been higher in developing than in developed countries: in the former the 1984 production was more than 35% higher while in developed countries the increase over the decade was about 15%.

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Particularly important was the increase in food production in Asia, almost 40%, and Central America, 33%.

In per capita terms of food production, the 1984 figure is 5% higher than the 1974 (12% in developing and 7% in developed countries). Africa is the only region that shows per capita declining production trends.

On the basis of the above figures, FAO and the experts in this field have been telling us for more than a decade that in terms of proteins and calories the food production is more than sufficient to supply the need of the present world population and even for a larger population. Some experts are of the opinion that the present production is enough to feed the six billion people anticipated by the end of the century. Furthermore, traditionally food-deficit countries like India and China are now net exporters of cereals, and of feed grains and rice.

In spite of the expansion in food production, the seventies were characterized by the syndrome of scarcity and the appearance of neo-Malthusianism. Food and famine, which reached their highest level with the African Famine in 1984/85, arise as one of the main concerns of the international community. The last 15 years have been the years of the so-called "food crisis which began in 1972, when the worldwide output of cereals declined sharply for the first time in over 20 years" [2].

This assertion almost accepted as a dogma was based on a superficial analysis of the situation and supported by a misleading paragraph of the working document prepared by FAO for the World Food Conference of 1974: "The present world food crisis, originating from a combination of longer term problems and temporary setbacks, suddenly emerged in a pronounced form in 1972. In that year the output of food in the world declined for the first time in more than 20 years... World food production of cereals, presently totalling about 1,200 million tons, had to increase on an average by about 25 million tons each year to meet the rising world demand" [3].

The situation was dramatised, as we can see in the following quotation: "In the early seventies the soaring demand for food, spurred by both continuing population growth and rising affluence, has began to outrun the productive capacity of the world's farmers and fishermen. The result has been declining food reserves, skyrocketing prices and intense competition among countries for available food supplies. Fundamental changes in the world food situation have left government institutions and individuals everywhere unprepared and vulnerable.. The world is now in a highly vulnerable position. In 1973-74, world reserve capabilities in relation to consumption needs fell far below any previous level in the postwar era to the equivalent of only twenty-six days worth of world consumption" [4].

The FAO statement was misleading because it examined the situation out of its historical trend. In fact the agricultural production fell in relation to the 1971 level, which was the highest ever obtained until the seventies, but the 1972 production was still higher than the 1970 one and 5.7 per cent higher than the average production of the years 1965/70. Moreover, a new production record was achieved in 1973, and since then the world food production has increased steadily. The 1831 million tons of cereals obtained in 1985 are more than 780 million tons higher than the 1974 level, implying an average increase of more than 70 million per year or 2.8 times the 20 million tons estimated as necessary by the 1974 FAO report.

The dramatic warning of the early seventies motivated the elaboration of plans to cope with future scarcities. New international institutions were created to deal with food and agricultural problems, financial resources were allocated and 24 million hectares in the United States withheld from production were returned to production.

The political component of the food issue was widely recognized: on the eve of the World Food Conference, the United States Secretary of State for Agriculture, Earl Butz, stated that "Food is a weapon", and a research report of the Office of Political Research of the Central Intelligence Agency (CIA), quoted by the International Herald Tribune, stated, *inter alia*, that "world food demand could give the United States a measure of power it had never had before — possibly an economic and political dominance greater than that of the immediate postwar II years". It added: "in bad years, when the United States could not meet the demand for food of most would-be importers, Washington would acquire virtual life-and-death power over the fate of the multitudes of the needy... Without indulging in blackmail in any sense, the United States would gain extraordinary political and economic influence..." [5].

This comment proved to be an accurate prediction. The United States export of agricultural products rose from 64 million metric tons in 1970, to 164 million tons in 1980 while the value of the agricultural exports climbed from US$ 7 billion in 1970 to nearly US$ 41 billion in 1980 [6].

Is it possible to believe in food scarcity, in the light of the above global figures of production? Among economists it is generally accepted that prices are adequate indicators of scarcity. In the case of agricultural products, the statistical analysis indicates that with the exception of few periods in the pre-war periods, the prices in constant US dollars experienced a long-term secular decline. From 1970 to 1983 the real price of wheat, rice and corn declined at an annual rate of 1%, 1.3% and 2.6%.

However, this prosperity is in fact a sort of economic disaster. A special report of *Le Monde* [7], commenting the record of cereals production of the EEC, entitled the report "Céréales: la crise. Que faire des surplus?". At the same time the North American newspapers reported the "bad news" of a record harvest of corn in the USA of 210 million tons, which, far from alleviating the financial agricultural situation, precipitated a larger crisis. In fact the farm export boom of the seventies came to an abrupt end, leaving North American farmers with an extremely heavy debt burden accumulated: in the last 15 years the net farm income has not changed, while farm debt has quadrupled. The result has been a debt-income ratio that suggests one dollar of farm income must now support nearly ten dollars of debt [8]. The US$ 213 billion debt of American farmers was equivalent to two-thirds of the 1985 Latin American debt (US$ 368 billion) [9].

In spite of increasing food production and surplus at the world level, still about 500 million people are undernourished and famine has been the issue that has concentrated the attention of the media during the last two years. By early 1985, the United Nations estimated that the number of people seriously affected by food shortages and in urgent need of food was, only in Africa, 30 million.

The persistent increase in food production, ahead of the increase in population, has been associated with the gradual deterioration of nutritional standards, the growing dependence of developing countries vis-à-vis the international market for the supply of food, and increasing poverty, particularly rural poverty.

The situation is particularly serious in Africa, where it is calculated that in the sub-Saharan region, between 60 and 70% of the population were, in 1980, below the poverty line and even considered destitute, meaning, in the first case, that their income per capita was below US$ 115 while, in the second, the income per capita was less than US$ 59 (at constant US$ of 1972). A recent report by UNICEF noted that since 1980 the average income per capita has constantly declined at an average annual rate of 4.1% and it is now between 15 and 25% less than 15 years ago. The statistics from 40 countries show that from 1979 in only two countries of sub-Saharan Africa the income per capita has increased, while in 35 it has declined between 1 and 40% [10].

The long process of stagnation, particularly in sub-Saharan Africa, contributes to give a rather gloomy perspective, so the World Bank noted that even with drastic economic improvements, the per capita income in sub-Saharan Africa will continue to fall during the 1985-1995 period, and probably up to 80% of the people will be by 1998 living below the poverty line [11].

The regional food and agriculture situation has been characterized by short-fall in food production, coupled with high levels of post-harvest losses and seasonal and cyclical problems (drought), which resulted in increasing dependence on food imports.

Africa has failed to achieve the minimum indicative goal of food production discussed by the World Food Conference, reaching only a rate of 1.9% against the recommended 3.9% between 1974 and 1983. The rate is decreasing since, according to FAO, the rate between 1979 and 1983 was 1.6% per year and during 1980 was a mere 1%. In 1985, cereal production in Africa reached a record of more than 54 million. However, in spite of this recovery, Africa is facing the deterioration of the food self-sufficiency ratio, which indeed dropped from 98% in the 1960's to 86% in 1980 with further deterioration during 1980-85. The per capita food production in the region has declined at a rate of 1.4% between 1979 and 1983 [12]. The food imports have therefore increased tenfold during the last two decades. In 1984, the imports were 7.2 million tons and the requirements for 1986 were estimated at about 8.5 million tons.

The consequence is a sharp fall in consumption, so the number of malnourished people is estimated to have increased from 80 million in the seventies to over 100 million in 1984. The evidence of rising malnutrition is particularly seen among children under five; UNICEF has indicated that of 67 million children under 5 years old in sub-Saharan Africa, 17 million or 25% were malnourished, weighing less than 80% of normal weight for their age [10].

In the case of Latin America it is calculated that 60%, or 65 million people, of the rural population live in poverty conditions, of which 35 million are considered destitute in relation to about 55 million persons living in poverty conditions in urban areas [13].

Between 1980 and 1984, the production of food per capita declined at a rate of 0.6% per year [14]. Associated with this situation, prices of food increased at a higher level than the inflationary process. Therefore, the real prices of food were in 1980, in almost all countries of Latin America, higher than those of 1970 [15].

Obviously, the lower income class is the most affected by this negative evolution as is reflected in the two following related facts. The first one is the increasing percentage of the family income allocated to food consumption. It has been estimated that around 70% of the Latin American population allocate between 50 and 75% of their income to food acquisition [16]. The second fact is that the food consumption is becoming less and less diversified *pari passu* with the declining quality and quantity of food consumption.

On the other hand, the medium and high income sectors of the population have been influenced by foreign patterns of consumption, increasing their demand for processed and semi-processed food.

The demonstration effect, by altering the pattern of consumption, creates a rather heterogeneous situation, particularly in urban areas, which is one of the reflections of the progressive internazionalization of the food system.

So we are now witnessing a very peculiar food crisis, characterized by increasing food surplus and stockpiling in the industrialized countries, and acute shortage, famine malnutrition and increasing poverty in the developing countries.

This situation leads automatically to increasing food insecurity and dependency upon foreign supply. Food security has been defined in different ways. One of the definitions refers to it as the ability of food deficit countries or regions, of households within these countries, to meet target consumption levels on a year-to-year basis [17]. A larger concept is given by Saouma, who defines food security as the capacity to ensure, at every moment, the physical and economic access of all the populations to the basic food they need. This implies that the food security policy has three basic objectives:

— to ensure the adequate volume of food production,
— to obtain the maximum stability in the flow of food, and
— to guarantee the access to available food for those who need it [18].

Thus malnutrition and famine are only the tip of a much bigger underlying crisis. To overcome this catastrophic situation, it is not sufficient to produce enough food; it is also necessary that people have access to adequate combination of food staples, that the production shall be sustained with minimum cyclical fluctuations (both of quantities and prices) and that each national food system reaches a certain degree of autonomy so that the dependency upon external supply will be minimized.

Food security is today affected by several factors which are not necessarily part of the food system. Among them it is possible to mention: fluctuation in food production which can be caused by climatic conditions, natural and man-made disasters, price fluctuations in international markets; employment and income generation of the population, fluctuations in the international monetary system, modification of capital markets, environmental growing problems and political decisions.

Today, the situation is becoming even more complex. Facing increasing internal surplus and slowdown of the world demand, developed countries decided to sell their surplus at subsidized prices. Thus the EEC displaced Uruguay from the Arab meat market by selling beef at a third of the internal EEC price, while a recent North American decision to sell the cereal surplus to the Soviet Union at subsidized prices has created great turmoil in Argentina due to fear of losing an important market with the consequent aggravation of its balance of payment situation.

As Amartya Sen said: "in the fight for market command over food, one group can suffer from another group's prosperity, with the Devil taking the hindmost" [19]. How can this paradox of poverty in the midst of plenty be explained? We will try to examine one of its aspects, the one related to technological innovation and diffusion in agriculture.

2. Technologies and the Role of Agriculture in Development

« Perché ragionare sulle cause e sugli effetti è cosa assai difficile ».
Umberto Eco: *Il nome della rosa.*

A careful analysis of the copious literature on Third World development reveals a heavy emphasis placed on industrialization, particularly through the import substitution strategy, relegating agriculture to a marginal role in the process of development. It was a tacitly accepted assumption that agriculture lacks autonomous development capacity and that industrialization will automatically drag rural areas into the development process.

In this context the role of agriculture was considered to be basically the one of providing cheap food, raw materials, and labour, and creating surplus to be transferred out of the sector in order to finance industrialization and economic growth. Hence the key strategy was to increase agricultural output. This position was supported by historical experiences and indirectly by theoretical approaches to the problem.

In relation to the first aspect, Kuznets's work demonstrated that the share of agriculture in the total labour force is very low in developed countries while the contribution of agriculture to the GNP decline *pari passu* with the increase of the income per capita [20].

Based on Kuznets empirical research, it was postulated that economic growth would be fostered by increasing the agricultural output and the transfer of the surplus generated in agriculture to other sectors of the economy, an approach supported by historical cases of industrialized countries which influenced developing countries' policies.

The beginning of industrialization in the U.K. benefited from the net transfer of resources from agriculture in the form of rent payments to landlords, taxes and later the repeal of the corn laws. Furthermore, the U.K. used to import large quantities of cheap food from abroad, thus depressing internal agricultural prices which resulted in unfavorable terms of trade for national agricultural products.

The early stage of development in Japan was characterized by a net transfer of agricultural resources and surplus towards the industry and other sectors; landlords invested in non-agricultural sectors and government revenues depended largely on land taxes. Finally, it is well known that the industrialization of the Soviet Union was made possible by the large transfer resources from agriculture.

At the international level it can also be asserted that the developing countries' agriculture has transferred surplus and resources to support the industrialization of the developed world [21].

Thus historical experiences were used to support the thesis that the role of agriculture was to provide cheap food and raw materials; and agricultural surplus to propel industrialization. For this purpose the surplus was to be extracted through different mechanisms, like landlord investment outside the agricultural sector, and/or impositive system over land and agricultural products, or finally by the import of cheap food products from abroad, which created unfavorable internal terms of trade for local agricultural products.

The history of Third World countries also reveals heavy transfers of resources from agriculture by a powerful landlord class which invested in non-agricultural activities. On the other hand, governmental revenues in developing countries depend largely on taxation of export commodities, mainly agricultural products, which in many of them are responsible for up to 90% of the foreign income revenue.

However, it is self-evident that a net transfer of resources has to reach an end if the agriculture is stagnant. In fact a continuous transfer of resources is not possible over a long period if the agriculture output does not augment. The mechanical approach is to adopt a policy that permits to increase the agricultural output and surplus, that is, a growth policy which not necessarily implies development. For this purpose a complete battery of economic tools were available. Agricultural development policies were therefore oriented to the maximization of the agricultural output through modernization, frequently favouring the expansion of large capitalized farms, subsidizing inputs, particularly imported inputs, implementing programmes for training in new technologies or to influence farmers' decisions for the adoption of more productive crop varieties, farming practices, or technological inputs, etc.

Certainly agriculture has been studied in relation to development but from particular and even isolated perspectives. One of these perspectives is the analysis of the agricultural sector as an exporter activity frequently linked to the plantation economy. In this perspective, agriculture was supposed to provide the resources necessary for the development of the country. The plantation economy has been largely studied, mainly in relation to their foreign private control.

The second issue that attracted economists and social scientists was agriculture as the root of a social, political and power structure that was impeding structural change and development in developing countries. A large part of the literature on agriculture in Latin America is focused on this aspect associated with the concentration of agricultural property, the *latifundio*, and foreign control over agricultural exports [22].

An important theoretical thesis was elaborated on the basis of the performance of primary products, particularly agricultural commodities, on the international markets. This thesis, known as the Prebish-Singer [23-24] theory of the secular deterioration of the terms of trade of primary products vis-à-vis manufactured goods, was converted in a sort of leitmotiv of ECLA and UNCTAD, permeating all their activities. The theory was partially based on the observed fact that the income elasticity for agricultural raw materials and food is less than the unity and that technological development in the industrial sector was oriented to increase the efficiency in the utilization of raw materials, thus reducing their consumption per unit of final manufactured product. As a consequence of these two phenomena, the international demand for primary products tends to grow less than proportionally in relation to income increase. Although the reasons argued are valid, they are not sufficient to explain the performance of raw materials in international markets. Furthermore, the argument was not applicable to all primary products.

In this approach we found a sort of fetichism and determinism, by which primary products, and in particular agricultural commodities, have an inherent character of decline in the relative price. The absence of logical economic argument to support this fetichism was commented elsewhere [24-25].

This negative aspect was reinforced with the argument that the export of primary products was dependent on the demand of industrialized countries, so the dynamic element was exogenous to developing economies, hence making the country more vulnerable to external hazards.

The grace stroke came from Hirschman, who stated that "agriculture certainly stands convicted on the count of its lack of direct stimulus to the setting up of new activities through linkage effects; the superiority of manufacturing in this respect is crushing" [26].

This definitive asseveration coincided with the thesis that economic growth could be achieved by promoting those sectors with larger backward and forward effects and their capabilities to create external economies [27-28]. In this context it was accepted that agriculture had very poor, if any, capabilities to stimulate growth in other sectors.

The concourse of these empirical facts and theories leads economists and decision-makers to dismiss agriculture as a source of economic growth and development, or at least to consider it as very limited in scope. So the objectives of agricultural policy were to increase the output through different policies, and mainly through modernization as part of a strategy that implicitly assumed that growth and development were the same thing. Furthermore, this approach was coherent with the prevailing post-World War II growth paradigm. It is important to examine the role of technology in the implementation of this approach.

The approach that prevailed during the fifties and part of the sixties was based on the promotion and diffusion of modern technologies [29] of developed temperate zones into developing countries in order to increase agricultural productivity. The purpose was to achieve rapid modernization of the so-called traditional or backward agricultural sector and a rapid growth in agricultural output. This approach was highly stimulated by the buoyant American agriculture that was adopted as a model and coupled with the concept of 'bridging the gap'. The obvious policy was the implementation of international programmes to diffuse the agricultural practice and technology developed in highly industrialized temperate regions in order to narrow the gap between the agricultural productivity of developed and developing countries. However, the failure of these international assistance programmes demonstrated the limitations of the model.

The interpretations of the failure of the approach moved along two basic lines. One stressed the need to increase productivity through the provision of new modern and efficient technologies, together with investment in human resources and in agricultural research. This approach was systematized by Schultz [30].

The second line emphasized the existence of structural barriers to rural development, basically land tenure, associated with highly concentrated economic and political power. Solon Barraclough's work [31] is among the most relevant on this line, which as a matter of fact gained large support in Latin America. The consequent political recommendation of these critics of the model was that agricultural and rural development was not possible without socio-economic structural reforms and particularly land reform.

Schultz's theory received unexpected support from the success of the new HYV developed at CIMMYT and, later on, at IRRI. Programmes were implemented for the purpose to provide industrial agricultural inputs, mainly fertilizers and pesticides, to which the new varieties proved to be highly responsive, together with training programmes. In this context the approach obviously received great support from transnational corporations.

The model based on the philosophy of the green revolution dominated the strategies for agricultural development of the sixties and seventies. From the point of view of the global production of cereals the results measured in terms of growth have been impressive. Yet rural poverty and social inequality are greater than ever and food dependency and insecurity have become a major issue in international economics and politics.

The first aspect has been highlighted by a group of scholars, namely Brown [32], while the regressive impact on land tenure and income generation in rural areas have been stressed by others, among them Griffin [33].

The assumptions that the green revolution technology was scale neutral, and the generator of productive employment in rural areas, proved to be, if not wrong, at least partially incorrect.

The approach to agricultural development of the post World War II period operated mainly from the supply side of the food system. This approach was also reductionist, in the sense that it focussed on the increase of output, neglecting the socio-economic impact of technological applications. Increasing unemployment associated with poverty and malnutrition shifts the attention to the demand side and the need to create economic conditions, in terms of employment and income generation, that will permit the satisfaction of food requirement of the large mass of the population. It was recognized that agricultural development cannot be achieved only by the increase of production and that hunger and malnutrition do not depend solely upon inadequate supply. It is necessary that the potential demand can materialise, and for this it is necessary to generate employment and income. Shortly the food problem must be approached from a systemic perspective rather than from the sectoral one, while technological innovation should be assessed and managed in order to optimize its benefits over the complete system, minimizing the negative impacts.

3. Technological Innovation in Agriculture

> « He had been eight years upon a project for extracting sunbeams out of cucumbers, which were to be put into vials hermetically sealed, and let out to warm the air in raw inclement summers. He told me, he did not doubt in eight years more, that he should be able to supply the Governor's gardens with sunshine at a reasonable rate; but he complained that his stock was low, especially since this had been a very dear season for cucumbers ».
>
> Jonathan Swift: *Gulliver's Travels.*

3.1. *Agricultural Systems and Technological Innovation*

In general the literature on technological innovation consists of ex-post analysis of technological historical trends. These analyses are largely biased by the commonly accepted idea that innovation is an industrial phenomenon, thus it tends to neglect the particular character of agriculture.

Studies of technological innovation explain historical economic trends through the comparison of labour and capital input data with the steady increase of production, or through the evolution of the aggregate production function. What was established was a close correlation between increase of productivity and growth of production. The emphasis on the technological effects on growth and productivity is coherent with the post-Keynesian paradigm, which links the growth of capital per capita with the resulting output per capita, defined by a given rate of change. Though scholars stressed different aspects of the phenomena, in general the analysis has been carried out on the basis of the aggregate function of production which suffers some shortcomings, in particular when referred to to the agricultural sector.

Among the shortcomings that are important to make explicit in this case it is possible to mention: the neglecting of the technology complementarities and synergetic effects on the social and natural systems; it ignores the historical context in which technological changes arise and the one into which technological innovations are transferred and adopted; it reduces the complete issues of technical change to a mechanical quantitative relationship between inputs and outputs in the productive process; finally it does not allow to explore long-term implications of technological innovation. The function of production is a rather static expression of the situation, allowing at the most a few speculations in the short term.

By adopting a reductionist approach — viewing technology only in the economic space and in relation to the shift of the production function — the economic tradition implicitly surmises its neutrality in relation to the rest of the system, because it ignores social and environmental effects which have no expression in the market.

In order to explore adequately the implications of future technology development and applications in agriculture, and their consequences for developing countries, it is important to revise briefly some characteristics of the agricultural sector and the function of production in relation to agriculture.

Agriculture can be considered as a system whose characteristics are shaped by natural conditions and by socio-economic, political and cultural phenomena. By natural factors is understood 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.

The dynamic interrelation of the above factors defines the potentialities and constraints of each particular geographical area.

Placed in a natural setting, during millenia mankind has developed farming practices that searched the optimization of the natural conditions, while tending to adapt to them. Empirical knowledge developed artisanal capabilities that permitted the domestication of several species which provided the basic commodities for the satisfaction of social needs. Such a domestication followed the ecological conditions of each particular area. Thus regions characterized by marked seasonality with regular precipitations during the year, and low evaporation, were found suitable for wheat culture, which has relative low demand for water, moderate requirement in terms of soil moisture and grows well during the cool weather of spring and fall. However, in the semi-arid regions, where the limited rain is not regularly distributed throughout the year, falling mostly in the warm season with high evaporation, more drought-resistant species were needed: sorghum and millet have therefore been the traditional crops of these areas. On the contrary, those geographical spaces with fertile, well drained soils and with moisture well distributed in the warm seasons are favourable to the production of crops like corn and soybeans.

Finally, in tropical areas where the growing season is long, the most appropriate crops are the everbearing plants and year-round sequences of food crops like roots and tuber crops (potato, cassava, yams, etc.) or peas, beans, nuts and oil seeds. Human groups adapted to each of these situations, developing different social and economic structures and institutions. The enormous accumulated empirical experience of agricultural practice, plus increasing scientific understanding and the development of technological capabilities, shifted the traditional process of social adaptation to the natural conditions towards the opposite position, that is, to the adaptation of natural potentialities to the requirements of the social system. Thus from a situation of social development being determined by natural conditions, that is the subordination of society to natural constraints, there is a shift towards the dominant attitude of society vis-à-vis nature. This has been possible by the increasing scientific knowledge and its application to technological development.

The main element in the development of modern agriculture has been scientific understanding and technological capabilities oriented by the economic criteria of maximization of yields of the storable products per unit of human effort. By and large, technological change in agriculture has been characterised by the increasing utilization of modern inputs oriented to raise the production per unit of land.

The effort towards the maximization of yields was oriented by few basic criteria: the profitability criteria, either at farmer [34] or at institutional level [35]; factor prices; on the assumption that they reflect factor scarcities and resource endowments; the satisfaction of particular market demands; and, the most appropriate utilization of particular natural areas.

These factors, however, played different roles in the areas where technology was generated and in those that adopted technologies developed elsewhere.

The leaders of technological development since the industrial revolution have been the developed countries, and in particular the United States, the European countries and later Japan. Agricultural technological innovations respond therefore to the climate and ecological characteristics of these areas and their socio-economic patterns, life styles and cultural backgrounds.

Technological development is a continuous process by which fundamental innovations are followed by improvement or pseudo-innovations. The combination of both types of innovations results in the shift of the function of production towards higher positions, enabling either larger outputs and/or improvements of their quality with the same quantity of factors of production; or alternatively the obtention of the same volume of output with less of at least one of the inputs.

Technological innovation is aimed at increasing yields and saving inputs through the modifications of methods or the shift from one crop to another, or by modifications of the quality of the factors of production. Thus mechanization implies a change in the method of production, while improved forms of machinery imply a change of the quality of the input.

A particular and very important aspect of agriculture is that the activity is based on the purposeful use of the empirical knowledge of local climate and ecological conditions for the optimization of the land use and local varieties. This labour skill and understanding is land saving. In the areas that lead the technological development the characteristics of the natural environment, the endowment of resources (capital, labour and land), as well as the market requirement were considered together in technological development and diffusion. Thus Japan developed an agricultural practice oriented to increase the productivity of land and at the same time to employ labour, since the first was a scarce factor and the second a relatively abundant factor. In the United States, on the contrary, farm land has been relatively abundant and labour has been the limiting factor, thus the practice was oriented to save labour by intensive mechanization.

The classification of technological innovation in capital, labour or land saving technologies, certainly does not preclude their simultaneous and complementary development and application. Furthermore, one technological change can easily lead to another. Thus increasing yields due to large use of fertilizers can make critical the scarcity of labour, inducing further mechanization. This in turn will require the standardization of products, inducing the restriction of crops to a few species among the existing ones; it can even induce a biological innovation for the development of a new variety (the case can be illustrated with the development of the mechanical harvester for the tomato).

Technological development was associated with the specialization of agricultural areas in accordance with their natural conditions, as the most convenient economic solution. This practice is well documented for the case of the United States, where the western plains are dedicated to wheat while the state of Iowa and in general the so-called "north Corn Belt", has specialised in corn and soybeans. Besides, technological development also permits specialization at the interior of each region. For example, in the northern part of the American plains, a variety of wheat that is planted early in the spring is used; however a winter variety, which is planted in the fall, is used in the southern part: Oklahoma and Kansas.

Obviously, economic factors also played a role in this intraregional specialization. As Griliches demonstrated in 1960 [36], hybrid corn entered first in Iowa and northern Illinois, not only due to natural favourable conditions, but also because in those areas the expected profits from the commercial production of hybrid corn seed were largest. Potential larger returns were explained by the existence of a larger market for corn seed, and a lower cost of entry in the region. Thus favorable natural conditions were reinforced by economic factors. The above reflection in agricultural technological development permit to go back to the basic element used in the analysis of innovation, that is the function of production.

3.2. *Land: a Black Box?*

The analysis of the function of production at the macro level identifies basically three factors: labour, capital and land.

The function of production describes a purely technical quantitative relation between what is fed in as inputs and what is turned out as outputs. Yet the production function does not tell us what the system does, and there are no indications of the characteristics of the process by which inputs are converted into outputs. Indeed the complete process is reduced to a list of quantities. The qualitative dimensions and the conditions that allow the conversion of inputs into a given product are completely neglected. This fact was noted by Samuelson when he stated that "the production function is a catalogue of all recipes found in a cookbook of the prevailing state of the arts for obtaining a given product out of given factors" [37]. An example of this misleading simplification of reality is found in Boulding, who stated: "an iron manufacturer knows that if he mixes so much ore, so much lime, so much coke and so much heat for so many hours, he will get so much iron" [38].

The production function is a black box; that is, a model that ignores the internal mechanism by means of which things are transformed. It provides only a superficial and mechanical explanation, but not an interpretation of the processes and behaviours occurring inside the system under study. It is only concerned with the global behaviour rather than with the internal structure of the system. It is also reductionist since it minimizes the role of non-observable variables or non-quantifiable dimensions. This argument does not deny the usefulness of the tool, but points to the fact that if what is wanted is to understand the process and/or to modify it, the black box must be broken open in order to disclose and permit us to understand what goes on inside it and to know the behaviour of the different elements. This is but another way of saying that the production function should be desegregated into its several elements, which, in their dynamic interrelations, constitute a more faithful picture of the process.

There are two additional problems with the production function: the assumption of the homogeneous character of the factors and the time dimension. The first one leads to a misleading conclusion in regard to the possibilities of substitutability of the factors, an aspect of increasing relevance in agriculture. The claimed homogeneity is even more misleading in those cases where the technological processes, having reached certain levels of sophistication, depend heavily on the particular characteristics of inputs. The complexity of the management of fertilizer and pesticide applications in relation to each particular ecological setting and crop variety illustrates this point.

The production function is static, it ignores time as an explicit variable. The problem of time has two dimensions: one relates to the fact that the function of production is supposed to illustrate a dynamic process which takes time to be accomplished. Higher productivity, reduction of costs and the saving of a particular scarce input are frequently achieved through innovations based on the reduction of the time required to perform a given process of transformation. The second aspect of time refers to the historical time or to the fact that a particular production function takes place in a particular epoch and is conditioned by the historical events of such a particular moment. Thus, a production function is constant, given a specific technology and the economic environment in which it appeared, but it changes when technology changes or if the economic environment is modified. Therefore, in these cases we have to deal with a different production function.

Two striking facts arise from the revision of the literature on the subject. One is the fact that the discussion has been largely concentrated on two factors: capital and labour. Land was either not included to explain technological change or it was treated very marginally. Directly linked with this is the second observed fact: that the production function is always used exactly in the same way, regardless of whether the problem under analysis refers to agricultural or industrial activities. This is but another way of saying that the mechanical application of the production function in both activities completely neglects the substantial differences between their structures and functioning.

The emphasis on the aspects of technological labour-saving versus capital-saving technologies has kept in the dark the third factor: land. In fact, following traditional Ricardian economics, land has been considered as a rather inert factor of production that generates rent. Rent is the portion of the produce of the earth which is paid to the landlord for the use of the original and indestructible powers of soil, (D. Ricardo [39]), an argument further developed by other economists. So Henry George stated that the rent or land value does not arise from the productiveness of land [40].

However, these assumptions have proved wrong. Land value can arise from the productiveness of soil, and unfortunately the powers of soil can indeed be destroyed. It has been indicated that the loss of arable land reached a total of 20 million square km., that is a larger area than the present area under cultivation, estimated by FAO at 14,7 million square km. This loss has occurred during the last 150 years and coincides with the initiation of what has been called "modern agriculture". Yearly, about 25 million hectares of land are being lost due to salinity, waterlogging, chemical degradation, chemical contamination, erosion and desertification [38].

It is not only a problem of loss, but also of deterioration of soil, that is, the reduction of its productive capacity due to the above mentioned phenomena. It has been calculated that the maize yield is reduced annually on an average of 250 kg/ha for each 3.5 cm of fertile land removed by erosion over a basis of 30 cm fertile land depth. In the case of wheat the loss is 108 kg/ha and for soybean 175 kg/ha [42].

This problem is extremely serious, since the possibility to incorporate new land into agriculture is becoming more and more difficult.

However, the analysis based on the production function ignores these facts. When land is explicitly considered, the treatment does not make any difference whether it is referring to an industrial or to an agricultural activity. Yet the difference is important. For industry, land means basically a space to be occupied by factories, or for stocking raw materials and final products. In agriculture, land means space plus the natural capacity to grow economic products on it.

Land is also soil, which is in fact a very complex system. It is a layer of the earth crust where living organisms and products of their decay interact with nutrients, water and other inorganic material in a process largely regulated by energy under specific climatic conditions. Soil is actually a complete system that catches rainfall and solar radiation and transforms them, which in the end permits the development of a complete process of production by which biochemical elements are used and transformed, thus permitting the growth of vegetation beneficial to human beings.

This process of transformation is in addition dependent on the close association of soil with climate. Agriculture is largely a solar energy harvester and processing system which can be affected by human intervention to the extent that the elements and processes that permit its functioning are modified. Land in traditional economics has been considered as something immune to any qualitative and quantitative change. The additional economic assumption is that land is a factor characterised by a relatively inelastic supply. But land cannot be included in the same category as other factors of production such as cement or ore. Land is itself a complete productive system, whose functioning has been largely ignored by economists, who considered land input as a stock variable measured by the physical amount of cultivated area (square measure: acres, hectares, etc.). Yet this resource has been used for millennia, and through empirical understanding farmers have discovered how to optimise the yield that can be obtained from it.

Later, human ingenuity discovered that the biological productivity of land can be stimulated through the application of specific inputs, e.g.: water, organic and non-organic fertilizers. Economists consider land as a black box into which inputs are fed and products obtained. Its efficiency was defined by the relationship between the labour and capital employed and the yield obtained. Thus, technological change in agriculture has been oriented, by and large, towards the use of modern inputs, raising productivity per unit of land used. The relation between outputs and inputs has been the unique criterion employed. Little, if any, concern has been manifested until very recently for the structure and functioning of this black box, at least by economists.

In the last decade it has become evident that land cannot be considered as a fixed indestructible factor: returns can diminish not only because land of inferior quality is incorporated in the production (Ricardian view), but also because available land is lost due to irreversible alternative use (e.g.: urban areas, dams, highways, etc.), and because its accelerated qualitative deterioration (soil erosion, acidification, salinisation, waterlogging, etc.), reduces its productive capacity. The loss of quality of land does not refer exclusively to the character of soil *per se*, but also to the fact that the biological processes that take place on it are becoming less efficient or requiring additional energetic inputs to maintain their natural productivity.

It is in this context that the frequent arguments concerning technology that saves land should be examined. A revision of the arguments along these lines shows that what has been saved is the spatial dimension of land while its natural capacity to produce biomass, far from being saved, has been reduced. Then the fact that given technologies permit to obtain more production from the same or even less acreage refers to a concept of saving land space, but indeed they are more intensive in the use of the soil's productive capacity. In the long term such a land saving technology can result in an exhausting intensive soil technology. This is why modern agriculture needs increasing subsidies of fertilizers, which result in increasing energetic cost. This approach proved to be economically feasible when fossil fuel prices were kept artificially low and readily available, or when government can provide large subsidies to the agricultural sector. However, not only the increasing energetic cost is establishing limits to this strategy but also the very fact that in the long term chemical subsidies have proved to be unable to restore the qualitative character of soil, and in particular its structure.

To enhance the capacity of land and to maintain a stable agricultural system in order to produce more food and raw materials on a sustainable basis require to increase the efficiency in the harvesting and transformation of radiation; to enhance the biological processess, to increase the efficiency of crops in the uptake and transformation of nutrients, to create the conditions for crops to grow in different climatic and soil conditions, and so on and so forth.

In order to maintain a stable agricultural system, or to increase the agricultural output from limited extensions of land, it is required that human ingenuity be applied to living organisms and their dynamic interaction. This implies the recognition that the principles that have oriented technological innovation largely based on its industrial character have reached a limit in their application to agriculture. A different technological approach, based on the very characteristics of the agricultural activity, must be developed and applied. This certainly does not imply the rejection of the available technology. It only means that new approaches more suited to the biological character of the agricultural system, must be developed and implemented.

3.3. *Economic and Biological Productivity*

An important structural difference between agricultural and industrial activities lies in the possibilities to disaggregate the latter into its individual technological components, and to organize them in an adequate time dimension. However, the elementary processes of agriculture are highly dependent on nature's chronological time lapse, which determines the time at which a process must be initiated and when it must be ended. Plants must be seeded at a very precise time and they take a definite time to germinate and to produce fruits. Within certain limits the time necessary to produce a single product cannot be shortened by a more intensive or extensive utilization of other factors of production. In industry, on the contrary, a productive process can be initiated any time independently of climatic and time conditions, and the time to produce a given or larger quantity, can, within certain limits, be shortened by a more intensive use of other factors, or by extending the normal time of work, e.g.: by the adoption of a second shift in the factory. In agriculture, once the available land is planted, it is not possible to shorten the period of production nor to anticipate or to increase the expected production in case of a sudden increase of demand.

Furthermore, the use of each component of the technological process in agriculture is determined by climatic conditions and related to the time the main product requires to grow. Each crop must be planted in a precise time and fertilizer must be applied at a well defined moment of the process of growth: it cannot be anticipated or postponed. Therefore a complete organization should be arranged accordingly. There are some consequences of this characteristic: first, in agriculture the different elementary components of the technological process cannot be arranged in line, that is, the time of production cannot be divided into equal intervals, allowing each technological component of the process, or group of them, to start at each division point, or to manufacture the different components of the final product simultaneously and to assemble them later.

The possibilities to arrange agricultural production in line are clearly limited. In each particular climatic region, crops are dependent on seasons, which define the time of the complete process. Any agricultural process is seasonal, meaning that it depends on well defined climatic sequences and their interactions with the biological and chemical processess occurring in each ecological area. It is this interaction that permits the growth of the plants. The seasonal cycles generate seasonal patterns of crop growth and consequently seasonal cycles of agricultural production of food and raw materials.

The consequences are twofold: industry is normally more flexible and allows more specialization than agriculture inside the same unit of production. Secondly, in agriculture there is an inherent idleness of the factors of production, while in industry, provided that the demand of the product is sufficiently large and regular, the production can be arranged so that no factor of production is ever idle, or at least the idle period for each of them can be minimized. This is why there is generally an impression of the overcapitalization in the agricultural sector. Yet this overcapitalization is indeed a consequence of the subordination of the productive process to the climatic conditions and the biological and chemical processes of nature.

Seasonality implies also a different approach to the time dimension. One of the characteristics of industrial technological innovation has been the reduction of the time necessary to produce a particular good. In agriculture the possibilities to shorten the production time are obviously limited. Moreover, since seasonal characteristics are different at each latitude, the period required to undertake particular tasks also differs and so do the requirements for labour and inputs.

This aspect can be illustrated by the different length of the rainy seasons in temperate and tropical regions.

The time aspect is also present in the characteristics of the outputs. In agriculture the products must be processed or consumed within a given period of time, for they are normally perishable or exposed to the threat of deterioration due to external factors (pests). Again, the time for transforming or for distributing them is conditioned by the characteristics of the product and should be done in a particular and specific period of time.

An important difference between industry and agriculture refers to the concept of productivity. Technological innovation, in particular process-innovation, has been largely associated with increase in productivity. Actually the use of the function of production is very much linked with this aspect. In industry productivity is always associated with a combination of several factors: scale effects, quality of the inputs, substitution of factors, better machines, trained people, organization, etc. However machines, equipment, etc., are inert elements. In agriculture we have to deal with living systems that have their own productivity, independently of man's intervention. Agriculture is largely a solar energy harvester and processing system, with a biological productivity defined in terms of the amount of harvestable organic dry matter produced per unit of land area per year, expressed in terms of dry weight or energy content of the total material produced. This type of productivity is associated with the natural process of photosynthesis.

In economics, productivity generally refers to the output per worker per unit of time achieved with the assistance of capital, tools, machines, etc. The gains are a greater supply of economic goods and/or the possibility to enjoy increased leisure.

Following the traditional concept of economic productivity, technological innovation in agriculture has been guided by considerations of cost minimization and technological efficiency, which stimulate the increase of the harvested material in relation to the area unit in a given time. Yields are expressed in terms of amounts of plant economic material produced in a given period of time, usually one year or one crop period, per unit of cultivated area.

The organic matter available in plant tissues is indeed the total amount of biomass which not necessarily coincides with the economic product. The organs of plants to be harvested, because of their economic interest, such as the grains of cereals, the grain legumes, or tubers and roots in the case of potato, cassava or sugar, are only a portion of the total matter produced, which is traditionally expressed in terms of dry matter. Thus the biological yield represents the photosynthetic efficiency of the plant to produce organic material while the economic yield is the part of the organic material which has an economic value in the market.

Normally, yields expressed in dry matter are higher in root crops or tubers and lower in grain cereals and grain legumes. For example, the average to good annual yields of dry matter production is 35 to 90 t/ha^{-1} yr^{-1} for sugar cane, 10 to 40 for maize, 8 to 35 for cassava, 5 to 20 for wheat and 4 to 16 for rice [43].

The difference between the biological and the economic concepts of yield is measured by the harvest index, that is, the fraction between the economic yield and the biological yield multiplied by 100:

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

The harvest index therefore represents the efficiency of the crop in converting photosynthesized material into an economically valuable material. From a different point of view, it is a measure of the distribution of biomass to the economically useful parts of the plant.

The harvest index, in the case of cereals, indicates the proportion of grain weight to the total plant weight, while in root and tuber crops, it refers to the proportion of the roots or the tubers to the total plant weight.

Technology has been oriented to the maximization of the production of those parts of the crop that can be harvested for economic purposes. So, through the selection and manipulation of species, the changes in the architecture of vegetables, the increasing energetic subsidies, etc., the growth and improvement of the economic parts of the plant have been stimulated. For example, in the case of new varieties of cereals, more energy goes into the grains, and less into the leaves, roots and stems. This means that in the harvest index, the numerator of the fraction has been artificially increased, while the denominator has been reduced. So technological development has been oriented to the modification of the harvest index, either through the improvement of the total dry matter production, that is the biological yield, or the modification of the factors of the harvest index.

The economic production and the harvest index are determined, not only by the crop itself, but also by the physical conditions in which the crop grows. Therefore, it should be considered that in both natural and artificial systems, higher rates of production can be obtained when physical factors are more favorable or when the natural physical factors are modified, for example, by increasing energetic input, in terms of fertilizers, or by irrigation.

In other terms, yields can be controlled if the farmer can afford to use manipulated varieties and/or to subsidize energetically the crops, enhancing economic productivity.

It has been demonstrated that certain environments are more favorable than others for specific crops. This extremely important aspect can be illustrated comparing high yield varieties in Northern Europe and tropical areas. The productivity of crops is highly dependent on photosynthesis, of which the key factor is solar radiation. In any part of the world, solar radiation depends on the day length, the angle of the sun, and cloudiness. At the equator the variation of day length is practically zero throughout the year, while it becomes larger when moving towards higher latitudes. This means a greater variability of day length, depending on the season, in temperate zones. So it happens that in Northern Europe, high yield varieties of cereals are receiving, at the ripening time, higher radiation, because in summer daylight is longer, up to seventeen hours. In tropical areas the possibilities of more daylight are limited, or do not exist at all. The same variety that can benefit from more solar radiation in temperate zones cannot do so in tropical zones because of the shorter daylight, up to five hours. In addition, in the tropics temperatures are higher all through the year. So crops have higher respiration rates. The consequences are that a larger part of the converted solar energy should be used in respiration, and less is available for grain production. This aspect acquires ever greater importance if agriculture suffers high water stress as happens frequently in tropical areas. Therefore in these situations larger parts of the gross primary productivity is dedicated to the maintenance of the plant and, consequently, the net primary production is reduced, hence the economic yield.

This is an aspect frequently ignored in the transfer of agriculture technology and in the comparison normally made between economic productivity in temperate and arid, semi-arid, tropical and sub-tropical regions.

3.4. *Productivity in Temperate and Tropical Areas*

The records of production achieved by world agriculture are the result of increases in productivity of the main crops, in particular corn, which in the United States more than quadrupled its average yield per unit of land between 1930 and 1975, from 20.4 bushels per acre to 86.2 bushels per acre, while wheat increase was 115%, rice 117%, potato 311%, and so on. Increases in productivity in developing countries have, however, been much less; so while cereals productivity in developed countries augmented in 1984 by 15.6%, the increase in developing countries was only 3.2%. And in particular cases like sorghum, while productivity in the United States reaches in some places 8 and even 10 tons/hectare, the average in developing countries is still 0.96 tons/hectare, and in Sub-Saharan Africa it is only 0.6 tons/hectare.

In general, average yields in temperate areas are almost twice those obtained in tropical areas, as can be seen in Table 1.

Increase of food production can be achieved by increasing the acreage of arable land and/or by increasing the production per surface area. Since the first possibility is very limited, efforts have been concentrated more on the second.

The increase of production per unit of land can be achieved by two means: increasing the productivity of crops by genetic selection, improvement, manipulation and energy subsidy in the form of fertilizers, or by the reduction of those constraints that hamper agricultural production, like diseases, pests, post-harvest loss, etc., using chemical products.

Available agricultural technology is largely based on energy in terms of fertilizers, pesticides, water and mechanization. The genetic varieties can achieve high economic yields if planted in favorable ecological and climatic conditions and supported by a great amount of auxiliary energy input. These aspects are important ones in transferring the new varieties to developing countries. It should

TABLE 1 - Average yields in the temperate areas and in the tropics.

CROP	Temperate area yield kg/ha	Tropical area yield kg/ha	Tropical area yields as % of temperate area 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
Soybean	1,620	1,249	55
Beans (dry)	1,079	640	59
Groundnut	1,667	1,036	62
Potato	18,056	8,704	48
Sweet Potato	13,594	6,881	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 environments » IRRI. 1983.

be kept in mind that if the local conditions are less favorable than the conditions where the varieties originated, then the auxiliary energy inputs should also be larger.

The above consideration takes 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 necessary to maintain the system functioning, then the picture is dramatically different. So while it is true that the developed countries, and the United States in particular, produce several times more per unit of agricultural land than developing countries, it is also a fact that such a larger production is obtained at costs ten times higher in terms of energy.

It is also in this context that the argument that the differences in economic productivity between temperate areas and tropical regions represent a great potential for agricultural production, provided that the available technologies will be transfered, should be examined. The question is: are the developing countries in a position to afford such high-energy intensive technologies, in particular bearing in mind that due to more unfavorable physical conditions the energy requirement will also be greater?

In addition, in tropical countries useful varieties must compete with a larger variety of indigenous plants, diseases and pests, factors that are considered biological constraints towards higher economic productivity. Tropical areas are rich not only in varietal diversity of useful plants but they are also richer in a large variety of pathogens and pests. To overcome these difficulties requires once again larger inputs, hence more energy subsidies under the present technological pattern. The magnitude of this additional requirement is difficult to estimate, however an indicator can be the fact that yield losses of crops due to weeds are calculated around 30% of the potential yield and that this percentage can rise up to 65% in some developing countries [44].

4. The Systemic Character of Technology

> ... « especialistas, harto llevados a particularizar las cuestiones, a dividir cartesianamente el conjunto en partes cuya multiplicidad nos hacía perder la visión del conjunto ».
>
> Alejo Carpentier: *El Recurso del Método*

The concept of technology refers not to a specific gadget or process, but to a complete set of methods, tools, instruments and machines designed to increase the efficiency of productive activities, or to replace man for those actions which either he cannot perform himself, or which could be performed more efficiently. Thus efficiency depends more and more on the existence of an interrelated ensemble of gadgets, tools, machines and know-how. Technology applications can be considered as an ensemble of interrelated operations. Techniques and operations are the functional and interrelated components of a system. The logical consequence of this is that the application of one or other technique depends on the existence of a given scientific and technological infrastructure. For the same reason, it is not possible to isolate the effect of a specific technique, because the effect is caused not only by the direct and primary impact of the application of the technique, but also by the combination of a sequence of interrelated effects triggered by the use of the technique. Thus it is not strange that technological development and application generates new, unknown or undesired problems [45].

The development and application of technology does not leave the socio-economic and natural system unchanged; it affects the rate of growth of the economy, the income distribution, and therefore, the balance of economic and political power, at the same time it changes the natural environment. Technology is therefore a crucial factor determining socio-economic impact and interaction on the biosphere. Therefore technology development must be assessed in the context of its holistic or systemic dimensions.

Historically, the systemic dimension has been largely ignored. The traditional compartmentalized and sectoral approach has neglected secondary, tertiary or unexpected effects of technology on the system. Efficiency is the basic criterion for the choice of technologies, and this same criterion orients scientifically-applied research and technological development, with the assumption that other effects can be considered as "externalities" of negligible importance. However, concrete experiences demonstrate that the effects are not minimal, nor are they neutral. They permeate the entire socio-economic and natural system, and are the causes of social, economic and environmental changes.

In order to increase productivity, different activities are implemented. In the case of agriculture, technological innovation is moving towards a more intensive use of biological productivity and of the biogeochemical function of the ecosystem in order to increase and accelerate extraction of resources. For this purpose, increasing and more diversified elements are added to the natural system. This increasing anthropogenic intervention produces a progressive artificialization of the natural system, which, in order to maintain its productive capacity and stability, requires increasing amounts of energy inputs to compensate for its loss of diversity and structural and dynamic changes [46].

Modern agricultural technologies imply the progressive artificialization of the natural system by concentration in few crop varieties of high productivity and the practice of subsidizing the natural system through increasing fertilization, irrigation, etc. The practice is supported by the increasing use of pesticides. The reduction of biological diversity has been a characteristic of mankind; however, it has been accentuated during the last century. The U.S. National Academy of Science reported that of 200,000 species of plants known, only 100 have been domesticated and only 30 of them contribute with 85% of weight of food and 95% of calories and protein consumed by man. Also only 8 species (wheat, rice, barley, maize, oats, sorghum, millet and rye) contributed to 75% of the total protein consumed [47].

Homogenization reduces biological diversity through the reduction of ecological diversity (elimination of species) and also by reduction of genetic diversity (concentration on few genetic varieties), for example only 4 varieties of wheat produce 75% of total Canadian crops, and more than half of Canadian prairies are concentrated on a single variety (the neepawa, paradoxically originated from germ plasm supplied by one developing country: Kenya, in the late 1950s).

The restriction of biological diversity in the developed world is done in order to increase productivity and is supported by scientific and technological capabilities.

The switch to productive strains, and homogenization of crop in developing countries, are also motivated by the need to increase productivity. However, in this case frequently the decision is made in relation to the requirements of the international market, with little or scarce consideration for the requirements of the local population and the characteristics of local ecosystems. Sometimes the result is the degradation of soil or the need to supply them with increasing amounts of fertilizers, which is not always possible due to the difficult economic situations of developing countries and the increasing price of fertilizers. The groundnut production in Senegal and Gambia shows a long declining tendency, due to the exhaustion of soils and inadequate fertilizing.

In Thailand, as the soil dedicated to cassavas impoverished, the production of cassava is expanded at the expense of forest. About 500,000 hectares of trees were burned annually in the late seventies to clear land for cassava cultivation.

The case is even more serious since the international market for groundnut and cassava pellet (mainly EEC countries) is declining and characterized by increasing protectionism, illustrated by the fact that the EEC and the Thailand government have agreed on a six-year "voluntary" reduction of cassava exports. This is a dramatic example of how the use and homogenization of ecosystems has not provided the expected economic gains but, on the contrary, has deteriorated the natural base for development [46].

In other cases, the results are the extinction of crop varieties adapted to the local ecosystem and highly resistant to local pests. New varieties do not have resistance to local pests; it is a known fact that the more genetically homogeneous the crop fields are, the higher is the vulnerability to large scale pests, diseases or weather changes. The rice homogenization in South East Asia has recurrently suffered devastations for these causes. Also the USA agriculture has been affected, as in the loss of 15% of the corn crops in 1970 due to the corn blight. The improvement of food productivity through genetic manipulation and monocultures should be examined together with the self-regulating capacity of those ecosystems where they are implemented. In the measure that resilience and homeostasis of natural systems is related to species diversity, the practice of monoculture is in fact undermining the capacity of nature to support the social system and its development in the long term. The conflict between the short-term economic benefits and the long-term uncertainty and risk should therefore be carefully assessed.

All together, the elements of modern agriculture create a net of socio-economic and natural effects, that are reinforced because of synergism and feed-back loops that are not possible to be tackled in isolation or on a purely sectoral basis. We are dealing with phenomena of a systemic character. Technology application does not create immediate single effects but rather multiple effects of primary, secondary and tertiary character appearing in different space and time spans.

Let us take an example: the objective of increasing food production through the use of fertilizers. Increasing food production will require ever larger amounts of fertilizers, since the area under cultivation is limited or will increase only slightly. The most immediate result will be an increase in food production, achieved in a relatively short time. However, nitrogen fertilizer will also affect water systems, soils, the atmosphere and, finally, human health, and in the long term can even reduce food production. It has been said that the large-scale use of synthetic nitrogen contributes to the reduction of soil organic matter, and therefore soil quality deteriorates as well. This will demand increasing artificialization of agriculture, which in turn will result in larger energy requirements and increasing costs.

A second effect is related to the ecological consequences of nitrogenous terrestrial fixation and its impact on the nitrogen cycle. Some years ago SCOPE estimated that at the rates of use of nitrogenous fertilizers, nitrogenous fixation would be equal to natural fixation by 1983, against only 6 per cent of natural terrestrial fixation in 1976. The fact has not been confirmed and the consequences of this are still largely unknown.

A third series of effects is related to pollution. It is well known that even in the most efficient agricultural system, that of the United States of America, crops absorb about 50 to 60 per cent of the nitrogen and 35 per cent of the potassium from fertilizers, and these percentages are much lower in certain crops in developing countries: nitrogen absorption in wheat and rice crops fluctuates between 34 and 39 per cent and 19 and 35 per cent, respectively. Typically, 30 to 60 per cent of nitrogen applied is directly absorbed into the tissue of the crop, and between 20 and 40 per cent is lost from the ecosystem with water or in gaseous form to the atmosphere. Not only is it wasteful and inefficient use of nitrogen; the fraction lost also causes disturbance of the natural system and constitutes a source of pollution. It has been reported that the crops harvested in the United States of America in 1977 removed only 7.6 tons, or only 36 per cent of the 21.1 million tons of nitrogen intentionally returned to the soil. Thus the potential for improvement of the efficiency of crop use of nitrogen is great [47]. Excessive fertilization is also resulting in eutrophication and nitrate contamination of drinking water. The first refers to increasing biotic activity, which in turn affects the availability of water. The second results in toxic effects like methaemoglobineamia, a health hazard with lethal consequences in children under one year of age.

It has also been asserted that synthetic fertilizer causes accelerated decomposition of organic matter, resulting in increasing carbon dioxide levels in the atmosphere, and finally, it is also said that nitrogenous oxide from fertilizer consumption goes to the stratosphere and reacts with it, depleting the ozone layer and altering the amounts of cosmic and ultra-violet radiation that reach human and in general earth biota.

There are also indirect or unwanted social and economic consequences. Fertilizers must be imported, and there is a net impact on the balance of payment, and imports of other goods and commodities should be reduced.

The use of fertilizers depends to a large extent on the purchasing power of the agricultural sector. Most probably, major tenants are in a better position to buy fertilizer, while poor farmers cannot afford it. The consequence will be an improvement in the competitive position of rich farmers and a regressive redistribution of income in rural areas, which in turn can result in a process of concentration of rural property (as happened with the "green revolution" in Mexico, Pakistan, etc.).

In order to avoid, or minimize these effects, distributive systems need to be created in rural areas, investment in water development will be required etc., etc.

The import of fertilizers has been stimulated through economic subsidies, tax exemption, etc., with the idea that the greater consumption will foster the modernization of agriculture.

Eutrophication not only reduces water availability but affects hydroelectric power systems, reduces possibilities of transport and affects the supply of fish protein and the economy of those communities organized around the fish activities.

Now the problem is considerably more complex, since the goal of increasing food production is pursued not through a single action (use of fertilizers) but rather by an ensemble of actions, including increasing mechanization, genetic manipulation, the use of pesticides, new irrigation schemes and new technological processes. Each of these actions produces a set of unwanted consequences, which in turn interact among them.

The "green revolution" is a clear example of this systemic character of technology and food production. The importance of the dramatic increase in production should not be neglected: in Mexico wheat production tripled in 35 years while in India it increased from 11 to 37 million tons in only seven years and the Philippines reached self-sufficiency in rice production. However, it should also be considered that the "green revolution" was applied in the best agricultural land.

The controversy on the "green revolution" shows that this technology has far reaching consequences and for this reason technology development cannot be evaluated solely on the basis of immediate direct outputs, but must be assessed on the basis of the set of effects and impacts on the socio-economic and natural systems, in the long as well as the short term.

5. The Chemical Component in the Technological Agricultural System in Developing Countries

The main chemical components of the present technological system are fertilizers and pesticides. Fertilizers have been considered the strategic input responsible for the increase of productivity in the last decade. It has been estimated that their increased utilization is responsible for 55% of yield increase in developing countries between 1965 and 1975 [49]. However, the chemical fertilizer consumption in developed countries is still about 2.2 times higher than in developing countries though it was 5.5 times higher in the early seventies.

The average consumption of fertilizers in Africa is only about 19 kg of plant nutrient per Ha of arable land against a world average of 78 kg. This figure is biased by the high consumption of fertilizers in Egypt, Zimbabwe, Mauritius and South Africa. Actually excluding these countries, the average scarcely reaches 8 kg per ha of arable crop land and is less than 1 kg/ha in countries like Zaire, Somalia, Niger, etc.

The Latin American consumption of fertilizers grew from 3.6 million tons in 1970 to 6.8 million in 1980, or at a rate of 8.5% per year. Yet during the last years a declining consumption of fertilizers has been reported. In South

America the average consumption is about 27 kg per ha but in Costa Rica reaches about 120 kg/ha. Asian average is 71 kg, a figure biased by the extreme high consumption of countries like Japan with 400 kg of nutrient, both Korean Republics with more than 300 and China with 125.

These levels of consumption are very far from the average of developed countries. In Europe it is 230 kg/ha with the highest figure for the Netherlands with 754 kg/ha and Belgium with over 500 kg/ha; Switzerland, Sweden, German Federal Republic, etc., consume more than 400 kg/ha.

These figures, however, are misleading because the developing countries' consumption of fertilizers is concentrated in the cash crops for export. According to Saouma, in Africa, there is practically no fertilizer consumption in the food crop production. In the case of Latin America ECLA/FAO indicated that 77% of fertilizer consumption is concentrated on cereals, sugar cane and oil seeds (soybeans). However, in per hectare terms the larger consumption is on sugar cane followed by soybeans, citrus fruit, bananas, green vegetables, potatoes and cereals. So they are mainly used in the banana and sugar plantations in Ecuador, in coffee and sugar plantations in Peru and Brazil [50]. Thus it is not strange that the fertilizer consumption in Barbados is 182 kg/ha and in El Salvador it is 102 kg/ha while in Argentina it is only 3 kg/ha.

Therefore the fertilizer consumption in developing countries is not motivated by the local demand for agricultural products but rather by the imperatives of the world market.

Another important aspect refers to the trends of this consumption in developing countries. In general and with few exceptions like China, India and Brazil, there is a trend to reduce the average level of consumption. The situation has been well documented in Latin America. In this region fertilizer consumption increased rapidly in the fifties at a rate of 15.5 and of 11.5 in the following decade and since then there is a clear deceleration in this trend. This deceleration obviously is not motivated by the achievement of a satisfactory level of consumption. Rather it is related to the increasing prices associated with the higher oil prices during the seventies and the increasing difficult situation of the balance of payments during the eighties that afflicts the majority of developing countries. Thus the developing countries' low demand for fertilizers is a consequence of their economic situation since they have to import more than 55% of the fertilizers they need. The lower world demand for fertilizers has resulted in decreasing prices, a trend which has been accentuated during 1986, when the export price in the Near East and Western Europe of urea and ammonium sulphate dropped by 41% and 37% respectively in relation to 1985 prices.

The weak international demand for fertilizers has resulted in idle capacity in developed countries while several local fertilizer plants in Africa and other developing countries were forced to close down.

It has been reported that in November 1985 the Canadian stocks of potassium chloride were 20.6% higher than in the previous year and that exports during 1985 fell by 32.2%. A similar situation was faced in the FRG, where cuts were imposed on potassium chloride production and the potash operations are to be closed for 9 to 11 weeks in 1986 [51].

We have again a very paradoxical situation characterised by surplus in one part of the world and scarcity in the other. As in the case of food, abundance and overconsumption characterise temperate developed agriculture, while insufficient utilization and lack of economic acquisitive capacity resulting in deficient consumption of fertilizers depict the situation in developing countries.

The increasing use of fertilizers attempted to overcome one of the limiting factors in agriculture, the one related to productivity. A second very important limiting factor refers to the biological constraints like diseases, pests and weeds.

Diseases, pests and weeds are biological constraints that reduce production and contribute to low productivity in agriculture. The average crop loss resulting from insects, diseases and weeds has been calculated as high as 35% of the potential production of all crops, with a higher percentage of 46% for rice and a lower percentage of 24% for wheat. These percentages differ depending on the regions and on the cause of loss. The higher losses occur in Africa and Asia, reaching 41.6 and 43.3% of their relative potential crop value. The lower ones refer to Europe, with 26% loss of potential crop value. The major causes are insect pests, with 11.3% loss, and the lower weeds, with 9.7%. Among regions percentages also show variations. Thus, in Africa weeds are the main cause of losses: 15.7% of crop value production, while diseases are the main factors in South America and in North America.

Obviously these differences are related to the dominant crops cultivated in each region. So insects constitute the main problem for rice and peanuts while diseases are important constraints for bananas, cassava and potatoes. Weeds are also the major threat for sorghum, maize and soybeans. Certainly the exposure to one problem does not exclude that crops are exposed to the threats of the others. So weeds are also a great constraint on rice culture and diseases also jeopardize growing of soybeans as it is possible to see in Table 2.

The combat against insects, diseases and weeds has been based on the large application of toxic chemicals. Agricultural consumption of chemical insecticides increased by 58% between 1972 and 1983, reaching the value of US$ 12.8 billion. The world consumption is heavily concentrated in developed countries with 85% of the total, and in particular USA that absorbs between one — third and one — half of the world consumption.

Quantitative information on the use of pesticides in developing countries is scarce, and reliability is frequently questionable. Yet there is no doubt that consumption in developing countries has increased during the last decade, as reflected by the fact that in 1983 they represented 15% of the world consumption against 8% in 1972.

In Latin America the consumption of pesticides increased during the last decade at a rate of 8.4% per year, passing from 77 million tons of active ingredients to 136 million tons. Of this total 49% is constituted by insecticides, 27% by

TABLE 2 - 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
Soybeans	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: S.H. Wittwer: An Assessment of Future Technological Advances in Agriculture and their Impact on the Regulatory Environment, in « Critical Food Issues of the Eighties », ed. by M. Chou and D.P. Harmon. Pergamon Press. New York, Oxford 1979.

herbicides and 24% by fungicides [50]. The first two expanded at a faster rate: 9.1% and 13.9%, respectively.

It has been estimated that Latin America represents about 36% of pesticide consumption of developing countries and that the Far East absorbs about 34%, the consumption of Africa being 16%. The balance is consumed in the Near East.

As in the case of fertilizers, the pesticide consumption in developing countries is heavily concentrated in cash crops and areas where the green revolution has been applied. In West Africa the use of pesticides for food crops is insignificant [52]. In Latin America the regional average volume of pesticides applied per ha is 4 times greater in cotton plantations than in the case of fruits, coffee, potatoes and sugarcane. During 1974-76 cotton cultures absorbed 39.6% of the pesticides consumed in Latin America [50]. It has been calculated that 70% of the cotton insecticide use is in the developing world [53] and that only the cotton production in El Salvador absorbs one fifth of all parathion used in the world [54]. 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 7 times more acreage than plantation estates [55].

Insecticides represent about 90% of the total pesticides used in Africa. In South East Asia also insecticides are the most important pesticides but its share of the total varies from about one-half to two-thirds of the total amount consumed [53]. The major use of herbicides in Asia and their growing consumption in Latin America are 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% of the arable land.

The increasing consumption in Latin America is largely explained by the greater acreage allocated to certain crops, particularly soybeans. The production of soybeans in Latin America increased during the seventies at an annual rate of 25.9% and accounted for 62% of the fifteen million extra acreage harvested registered in the region [50]. As a matter of fact, it is important to note that 90% of the soybean pesticides world consumption is applied in the USA, which also utilize 60% of the maize herbicide world consumption [53].

The expansion of pesticide application in developing countries has been largely stimulated by governments through different measures. The most frequent has been tax exemptions or reductions, low cost credit, subsidized prices, etc., which make them cheaper, hence encouraging their use. This is a particularly important aspect since most of the pesticides consumed in developing countries are imported. In Brazil, a consumption of pesticides is calculated at US$ 500 million per year [56].

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 subsidized pesticides grew from 5,100 tons in 1978 to 15,100 tons in 1982. The level of subsidy as a percentage of the retail cost is as high as 89% in Senegal, 83% in Egypt, 82% in Indonesia, 87% in Ghana, 44% in Colombia, etc. These subsidies imply a substantial cost for governments, that has been estimated at about US$ 200 million in Egypt, about US$ 128 million in Indonesia and US$ 70 million in Colombia [57].

More than 600 pesticides are available on the market. However, the reliance on this single line of crop defense has proved to be self-defeating due to several factors: among them high and increasing cost related to its energy-intensive character; increasing pesticide resistance, destruction of natural cybernetic mechanisms of control, outbreak of secondary pests, reduction of pollinators and health hazards.

The high cost of pesticides is due to their energy-intensive character and to the methods and practice of application. Pesticides are carbon-based compounds, synthesized 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. It has been calculated that the K/cal. for the production of 1 kg of active ingredient varies between 13.810 for methyl parathion and 108.000 for carbofuran in the case of insecticides; and from 24.200 for 2.4 D (dioxine) to 109.520 for paraquat in the case of herbicides. The energy consumption is lower in the production of fungicides: between 15.250 and 27.380 K/cal [58].

Aerial Drift Spray is the main technology used for pesticide application. The inefficiency and wasteful character of this technique is demonstrated by the following data. More than 40% of applied pesticide is normally out of the target area, 15% out of the target crops, 41% out of the target insect and of the 4% near the target insect, 75% is not in contact with it. It has been canculated that less than 1% of the total applied pesticide is absorbed by the insect through contact, inhalation and ingestion [59]. Furthermore, it has been reported than only 0.03% of the applied insecticides are absorbed by aphids on bean cultures, and 0.02% by mirids on cocoa [60].

This wasteful use is magnified by the practice followed by farmers who apply pesticides according to the preset schedules prepared by sellers and not when needed in response to actual pest threat to a particular crop or ecological area. If pesticides are applied only when necessary and in relation to specific pests, the actual use of pesticides by USA farmers can be cut by fifty percent with no effects on crop production [61].

The situation is even worse in developing countries. For example, only 44% of 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 [62]. This wasteful use reinforces the negative environmental impact associated with growing pesticide resistance.

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 the historical pattern of chemical control.

In 1977, the FAO reported that in 12 years the number of pesticide-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.

Increasing resistance is associated with the disturbances of the natural cybernetic mechanisms because insecticides are not target specific, which means that they kill not only the pest organisms but also other species, including their predators and parasites. The result is resurgence of pests and even the outbreak of new secondary pests. Secondary pest outbreaks refer to the development of potential harmful organisms to a pest character as a consequence of the chemical destruction of their predators or their migration. Among important outbreaks of resistant pests can be recalled the destruction of 263,000 tons of rice by brown plant hoppers in Indonesia during 1975 and the destruction in Mexico of 280,000 ha of cotton by the boll weevil. In the case of weeds it has been demonstrated that the chemical destruction of one weed infestation by chemical compounds leads to the replacement by new species of weed not vulnerable to the herbicide. For example, water hyacinths were replaced by other weeds when treated with chemical herbicides: in Florida they were replaced by alligator weeds and in Sri Lanka by salvinia.

The failure of this chemical approach is reflected in the fact that crop losses, far from being reduced, have increased in the last 30 years. Table 3 shows that in the USA the total loss increased from 31% to 33% of potential products between 1948 and 1974 and the total cost of control rose from US$ 8 billion to 18 billion. The case is particularly dramatic for the insecticides, where the cost increased 3.8 times and the loss almost doubled. As a matter of fact the loss has been reduced only in the case of herbicides.

On the other hand, pesticides and in particular, herbicides, have been used to replace labour and mechanization for weed control, which, while responding to the resource endowment of developed countries, when applied in developing countries results in a negative effect because it displaces labour in a situation where what is needed is precisely the opposite effect, that is, the creation of new jobs.

In addition, the health hazards posed by the application of chemical pesticides have been a matter of increasing concern. Data is available on direct human poisoning, but scarce information on the chronic effects resulting from the exposure to low level dosage during a long term. It has been estimated that only in the USA there is an average of 150 deaths per year and more than 100,000 cases of poisoning per year due to pesticides. The ICAITI in its turn reported that between 1972 and 1975 there were more than 14,000 poisonings and 40 deaths in the cotton plantations of the Pacific coastal plains of Central America [64]. In the Tiquisate area, in Guatemala, it has been reported that 30 to 40 people are treated daily for pesticide poisoning [64]. Finally, WHO statistics indicate that 490,000 people are poisoned by pesticides every year and that at least 5,000 die.

These problems faced by chemical technology in agriculture suggest the need for a new technological approach.

TABLE 3 - U.S. Agricultural Cost of Control and Crop Losses Caused by Pests.

	(billion dollars)								
	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

Source: Pimentel *et al.*, 1978. Socio Economic and Legal Aspects of pest control in « Pest Control Strategies ». Academic, New York.

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6. The Promises of Biotechnology

> — « I can't believe that », said Alice. « Can't you? » the Queen said in a pitying tone. « Try again: draw a long breath, and shut your eyes ».
> Alice laughed. « There's no use trying », she said: « one can't believe impossible things ».
> « I dare say you haven't had much practice », said the Queen. « When I was your age I always did it for half an hour a day. Why, sometimes I've believed as many as six impossible things before breakfast ».
>
> Lewis Carroll: *Through the looking-glass and what Alice found there.*

Biotechnology is based on the application of accumulated empirical knowledge to the manipulation of biological processes of nature in order to improve production, to modify elements and products, to transform them and finally to consume them. Agricultural intensification depends on the possibilities to affect the growth of the plant, the efficiency of nutrient uptaking and conversion, the reduction of their vulnerability, and, finally, the identification and domestication of new species that can expand the spectrum of useful plants.

The key natural process of agriculture is the harvesting of solar radiant energy and its conversion into chemical energy known as photosynthesis. Photosynthesis efficiency is calculated between 0.5 and 1.3 in temperate areas and 0.5 and 2.5 in tropical or subtropical regions. (Obviously the efficiency varies depending on the crop; so corn, sugarcane and sunflower are two times more efficient than tomato, tobacco or beans). Experts are of the opinion that rates of 5 and 6% are theoretically possible [65]. Biotechnology can contribute to the achievement of this objective in two ways: by improving the absolute net rate of photosynthesis and by extending the time over which optimal photosynthesis is carried out. The enhancement of photosynthesis requires the identification and control of the mechanisms that regulate wasteful processes, in particular photorespiration, and of the mechanisms that regulate the yields; the manipulation of hormonal mechanisms responsible for flowering and leaf senescence; the improvement of plant architecture and anatomy and the improvement of cropping systems.

The practical utilization of methods for the improvement of the photosynthesis is still at a very early stage and will be dependent on the identification of individual genes, the selection of DNA or RNA, their incorporation into a suitable vector, the stabilization of new DNA in the genome of the new host and so on. This is clearly a long-term task, and practical applications are not expected in the near future.

The possibilities to increase agricultural production depend on the ability to improve the natural process of biological fixation, which supplies an estimated amount of 175 million tons of nitrogen annually or about 70% of the total requirements, the remainder being supplied by the application of modern technology of chemical fertilizer plants.

During the last two decades increasing efforts have been dedicated to the study of biological nitrogen fixation. Two phases can be depicted: during the sixties advances were registered in the understanding of the biochemistry and physiology of nitrogen fixation, while in the seventies efforts have been oriented more towards the genetic aspects. The advances achieved in biotechnology research, particularly in cell and tissue culture and genetic engineering, are at present being applied for the improvement of the biological process of nitrogen fixation.

Since legumes are rich in protein and have the capability to fix nitrogen through their association with particular microorganisms, it seems logical to orient the attention to them first. It has been estimated that at present legumes in association with rhizobia fix at least 35 million tons of nitrogen yearly. Nevertheless, legumes obtain only 25 per cent of their nitrogen from nodulation, 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 the limiting factor for leguminous growth is the 25 per cent of nitrogen fixation through nodulation. Any increase in this percentage can result in more efficient agricultural systems. In this context the existence is known of different strains of rhizobium with different capabilities to fix nitrogen and that rhizobium is affected by different biological stresses. For example, soil acidity and alkalinity have been mentioned as one of the reasons to reduce nodulation. Thus acid soils, in particular in tropical regions, constitute a major constraint to legume expansion. Rhizobium is also sensible to drought as well as to high temperatures. It seems therefore important to identify the 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 most suitable strains.

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. The importance of this fact can be appreciated considering that if the period of active nitrogen fixation in the soybean nodules can be extended by only 10 days the effective nitrogen fixation can be doubled.

Finally, a major limitation arises from the specificity of rhizobium-legume symbiosis and their local climatic and soil conditions, or the fact that specific strains of rhizobium work well with a particular legume host and not with others, and their efficiency depends also on the ecological conditions, which vary in each geographical location.

The above comments suggest several possibilities to increase agricultural and food production on the basis of potentialities of rhizobium-legume symbiosis, and in particular the capacity of rhizobium to fix nitrogen. These possibilities range from the expanding of the use of legumes, including the identification and formation of those legume species not yet domesticated, the inoculation with rhizobium, and finally to the application of genetic manipulation for the creation of varieties that can fix the nitrogen they need.

The production of inoculants is to a large extent locally conditioned, depending on each species. In the United States about 30 million acres of soybeans are inoculated yearly with an annual nitrogen fixation calculated at more than 110 kg per ha. The advantages of inoculation are that it requires low capital, the transport costs are minimal and the technique itself is relatively simple and can be easily applied in rural areas of developing countries, where, besides the fact that it can be done in accordance with the local requirements, it can also generate additional jobs.

The increasing knowledge on genetics offers the possibility to manipulate the symbiosis itself by acting either on the rhizobium or on the plant host. For example, one approach is to increase the photosynthetic capacity of the plant, which in turn will provide more energy to the rhizobium. Another approach is to improve the strains of the rhizobium, increasing their capacity to fix nitrogen. Still another possibility is a nitrogen fixing microorganism so that they can live in symbiosis with a different host: e.g., rice or wheat. This approach probably will also require modifications in the host plant. Apparently the possibility of achieving positive results in this way is limited at least in the medium term. A third approach now being explored is the modification of some bacteria already living in the roots of the cereal in order to make it capable to fix nitrogen, thus benefiting also the plant. Another approach consists in the development of a new variety of cereals able to fix directly the nitrogen that is needed, by the incorporation of nitrogen fixation genes into the cell of the plant. This last 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 nif genes have been identified in the nitrogen fixing bacteria, requiring therefore an enormous capacity of genetic manipulation.

A second natural symbiotic process of nitrogen fixation involves frankia and non-leguminous plants, mainly woody shrubs and trees. About 145 species of plants of this type are known, casuarina being the best known. It has been noted that in Senegal in the soil around casuarinas the nitrogen increases at a rate of about 60 kg per hectare. In addition casuarina has a symbiotic relationship with other microorganisms and in particular with mychorizal fungi, which facilitate the uptake of minerals, especially phosphorus. For this reason casuarina is considered very convenient for the recovery of deteriorated soils, hence for the expansion of agricultural land.

Another natural process of symbiotic fixation of nitrogen occurs with the association of the fresh water fern called azolla and the blue green algae known as anabaena. This association, which is one of the most efficient from the energetic point of view, has been used in China, Indonesia and other Asian countries for centuries for the production of green manure and forage. The azolla-anabaena symbiosis can fix between 100 and 150 kg of nitrogen per hectare per year in approximately 40 to 60 tons of biomass if multiple crop growth cycles of association are practiced over a year. This amount of biomass can be achieved because azolla vegetation can double in about 5 days. However, under favorable conditions the normal amount fixed is between 50 and 75 kg/ha per crop and can be achieved with an active growth period of 6 weeks. Dead azolla decompose in the soil, releasing the nitrogen compound which becomes then available to the plant which it is intended to fertilize (traditionally rice). One crop of azolla applied to paddy rice is equivalent to the application of 30 kg/N2 per hectare of urea [66].

Azolla is suitable for double cropping of rice in irrigated areas. Recently rice fields in California have been inoculated with wet azolla, yielding 75% of the nitrogen required. It is believed that adequate selection of strains that can multiply more rapidly and can withstand extreme temperature can result in the increase of the azolla efficiency. An additional advantage of the azolla derives from its high protein content: on a dry weight basis it contains around 23.8 per cent crude protein [67]. For this reason it represents an important source of feed. In China azolla has been used up to 50% in the diet of pigs, and one hectare of green azolla provides enough fodder for 200 pigs [68].

The asymbiotic fixation of nitrogen at present being investigated and applied refers to the utilization of blue green algae (BGA) and 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.

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

The studies done in Egypt and India demonstrated that the inoculation with BGA is equivalent to the application of 24-48 kg/N/ha, with the additional advantage that algalization leads to increases in the organic matter component of the soil, hence augmenting its fertility. As in the case of rhizobium, the BGA presents some local characteristics, thus normally it is considered that the BGA used for the inoculation should be from the same area as the one where it will be applied. The inoculation of paddy rice with BGA was initiated in Egypt, where inoculated fields gave 26 per cent more than those without inoculation. This innovation resulted in increasing returns at the governamental level which produces the inoculants for selling to the farmers. Farmers obtained higher returns due to the reduction in the use of chemical fertilizer and the increasing yield obtained [69].

In India the Agricultural Research Institute is providing the peasant with the starter culture of BGA. It was calculated that from an area of 25 square meters it is possible to obtain, every fifteen days, about 100 kg of algae supplemented with phosphate, resulting in a benefit of between 20 and 30 kg nitrogen per hectare per season. An additional advantage of the BGA is that it can be stored in dry form without losing its reproductive capacity, so the dry material can be used at a later date directly in the paddy fields or as starter for new algae production.

Biotechnology is expected to have a major role in the attempt to overcome agricultural limiting factors associated with environmental conditions, pests and diseases. The problems associated with chemical inputs have activated the interest in this research on alternative methods for the control of pests and disease and for the study of plant-resistant factors. Several approaches, and the combination of them, are possible.

One approach is oriented to the increase of plant resistance. In relation to diseases, different genes of particular crops are known as the ones that produce resistance to specific pathogens. It is also known that resistance to environmental conditions is dependent on genetic inheritance. Tissue culture is a useful technique for the identification and selection of resistant traits; while resistant factors can be transferred between species by protoplasmatic fusion, genetic engineering is the final step in the attempt to obtain resistant varieties.

Two approaches can be followed in order to obtain resistant varieties. The first refers to varieties resistant to diseases, pests or environmental constraints like salinity, drought, etc. A second approach is the use of biotechnologies, and in particular genetic engineering, to obtain varieties that can be more resistant to chemicals or more responsive to them.

The second approach has important economic implications, in particular for crop rotation and the new concept of non-tillage agriculture. For example, one crop can be resistant to a particular herbicide but the following one in the rotation process will not. Therefore the latter cannot be planted on a field treated with such an herbicide. To illustrate this situation it is possible to quote the fact that corn is resistant to triazine herbicides, but soya is not. Hence soya cannot be planted after corn when the latter has been treated with triazine.

The interest of the chemical industry is, in this case, to obtain a soya variety resistant to the specific herbicide. However, this approach, far from reducing the need for spraying crops with chemical compounds, is in fact increasing their consumption, with the obvious additional economic and environmental consequences.

A second approach is the application of biotechnology for the production of microbial pesticides that can replace chemical ones. There is a large area of research and a potential market for bacterial, viral and fungal pesticides. Bacteria can synthesize insecticidal toxins, virus can be used to create diseases in noxious insects, and fungus can be used to infect both noxious insects and their habitats.

In relation to bacteria, the bacillus Thuringensis is now well known and a bacterial insecticide based on it has been on the market for at least 30 years and successfully applied in the United States during the 1981 gypsy moth invasion.

The attraction of viral insecticides is that they are target-specific and harmless to non-target life forms (contrary to chemical pesticides that are not target-specific).

The most attractive group of viruses is the Baculovirus group, which can be grown by the tissue culture technique. However this technique, though simple and easy to control, is still too expensive vis-à-vis traditional methods. Baculovirus has been successfully applied in Rio Grande do Sul and Parana in Brazil for the control of Anticarsia Gemmatalis in soya cultures at a cost 75 per cent lower than chemical control [70].

Successful stories of fungal utilization for pest control in tropical countries are known. In Brazil the Metarrhizium Anisotliae has proved to be very effective for pest control in sugarcane, soya and coffee plantations. The State institution

Planalsucar is producing inoculum at 18.3 per cent of the cost of traditional pesticides. The fungal pesticides have an efficiency of 75 per cent and permit the control of Mahanarva Posticata and Diatraea saccharalis on sugarcane plantations in the States of Pernambuco and Rio de Janeiro [70].

A further approach that can be used particularly for weed control is based on the capacity of some plants to avoid, tolerate or recover from the effects of natural enemies. These plants are called Allelopathic and can produce substances that are toxic to the competing weeds. Similarly, it is known that some plants have the capacity to produce insecticides that impede their being eaten by insects.

Finally, the group of biotechnological techniques known as tissue culture has an important role in the propagation of healthy plants. This group of techniques permits the vegetative reproduction and propagation of plants from parts or organs removed from living plants, such as leaf sections, anthers, pollen, meristems, embryos, protoplast and single cells. So *in vitro* culture of meristems leads to the production of uniform disease-free planting material. Anther culture is based in haploid microorganism manipulation making it possible to shorter the time needed in the selection of genes and therefore shortening the time required by traditional plant breeding techniques. Cell culture is based on the use of somatic cells and is a process that permits to investigate mutagenic characters and obtain somoclonal varieties which are used for testing new genotypes in relation to particular environmental stress. Embryoculture permits to introduce particular traits from one species into another, improving traditional breeding methods.

Finally, protoplastic techniques consisting in the fusion of two denuded cells, a process called somatic hybridization, make it possible to obtain new plant varieties.

Tissue culture is being widely used for the propagation of ornamental plants that can obtain high prices. However it is a technique that can be applied in developing countries for the improvement of local traditional crop cultivation. In particular, clonal propagation and meristem culture have the following advantages: rapid multiplication of plant materials, production of disease-free material, production of uniform plant material, all-year-round propagation of plant material, more rapid development of improved varieties, better conditions for long-term storage and international exchange of germoplasm, processes of propagation and reproduction independent of climatic or environmental hazards and constraints. The application of tissue culture in its different approaches is not developing at the same pace; in the short term the advantages of rapid uniform propagation of disease-free plant material appear more feasible, while anther culture and protoplastic fusion are producing concrete applicable results only in the medium term. Finally, the practical application of somatic hybridization, chromosome and gene transfer can be considered as a long-term objective, meaning 8 to 15 years.

The application of *in-vitro* clonal propagation has been successfully applied to recover areas cultivated with cassava that were destroyed in 1972 by the frog-skin disease and Caribbean mosaic disease in the Cauca valley in Colombia. In the early eighties the propagation of disease-free clones of a new variety permitted to duplicate and triplicate cassava yields and recover the acreage dedicated to cassava. Similar success has been achieved by IITA, Ibadan Institute for Tropical Agriculture. The improved varieties obtained at IITA have already been distributed in Nigeria, Zaire, Sierra Leone, and new reports refer to 17 countries that are incorporating the new improved varieties.

7. Conclusions

« You see things, and say why? But I dream things that never were, and I say why not? ».

George Bernard Shaw

A glance at the main characteristics of the world agriculture and food system reveals paradoxical situations and alarming trends which suggest the need for new innovative approaches to agricultural development policies.

Although historical experiences indicate that the share of agricultural contribution to the national income and employment declines over the long term, it seems that this trend cannot be forced or accelerated. The reduction should be the result of a process of development rather than an objective in itself. Furthermore, it seems wrong to identify the above-mentioned historical trends with a lack of dynamism of agriculture and from this assumption to assign to it a secondary role in development.

The post-World II development policies surmised that industrialization would draw agriculture and rural areas into development. However, after more than three decades this assumption did not materialize. Facing this situation and agriculture being the basic economic activity of developing countries, it appears relevant to revise the thinking about the agricultural role in development. In this revision agricultural development should be considered in a broader analytic framework and not only as a backward or traditional sector, from which economic surplus is being pumped out to support other sectors' expansion.

Two important interrelated phenomena of the post-World II era should be carefully assessed: the progressive internazionalization of agriculture and food systems and its increasing interrelationship with industry.

Internationalization affects agricultural development from several different angles. The transnationalization of food consumption patterns changes habits and diets, hence the qualitative characteristics of the demand. Simultaneously the shift from vegetal protein consumption to animal protein consumption, particularly in developed countries, influences in a great measure the characteristics of international demand for agricultural commodities. The increasing dependence of developing countries upon their export of agricultural commodities implies a greater integration in international markets and greater vinculation with the world monetary and capital market. This aspect is extremely relevant because increasing instability in international financial systems leads also to greater instability in international commodity markets. This instability is aggravated by growing protectionism and the fight for market control in a situation characterized by production surplus in developed areas.

The greater needs for foreign currency to compensate the deterioration of the terms of trade of developing countries and their increasing dependency on food imports add new pressures on international agricultural commodity markets.

The transfer of technology promoted for the "modernization" of developing countries' agriculture strengthened the internazionalization of the agriculture and food system.

The increasing integration of national agriculture and food systems into an international system moved *pari passu* with growing interrelationships between agriculture and industry.

On the demand side, the increasing industrialization of food through the creation of new products and processes and the opening of new markets are clearly associated with changing consumption patterns. On the supply side, agricultural production becomes more and more dependent on industrial technological inputs. In both cases it is possible to see the growing role of transnational corporations and the entry into the food system of transnational corporations not traditionally concerned with food or agriculture.

Despite this phenomenon, agricultural policies continued to be shaped in the narrow sectorial approach, neglecting the above-mentioned greater interdependencies.

In relation to technological innovations, two aspects of the above phenomenon should be noted. The first is that in the process of international integration the ecological difference between regions, and especially between temperate and tropical areas, were largely ignored. Secondly it has been surmised that technological innovation has the same characteristics and effects in industry and agriculture. Yet agriculture's dependency upon the natural system makes agriculture completely different from industry. In particular, the agricultural dependency on a regular ecological and climatic cycle, the seasonality aspects, the structural complexity and functioning of natural cycles and their influence on agricultural productivity are among the main aspects that should be considered in technological innovation and diffusion in agriculture.

So, while the increasing integration of agriculture into the international economy requires a wider economic approach, the specificity of the ecological characteristics of agriculture demands a more exhaustive micro-economic method. Macroeconomics has proved to be impotent to consider the specific aspects of agricultural supply, particularly those concerning productivity. In its turn micro-economics is insufficient as an instrument of economic policy in an international interdependent world.

Thus a new economic approach in agriculture cannot choose between macro and microeconomics, but rather should integrate both.

Furthermore, it also appears that the problem faced is not only economic. Ecological characteristics contributed to shape social and cultural institutions, which suffer the impact of international interdependency and of increasing technification in agricultural production.

Increasing agricultural output has proved to be insufficient for the achievement of development. Distributive, social and environmental aspects suggest that economics alone is not an adequate approach and interdisciplinarity is a must.

Technological innovation should be included as a central issue in the revision of thinking on agricultural development and has to play a strategic role in agricultural development policies.

The health, social and environmental drawbacks and the economic consequences of the present technological pattern should be considered in the assessment and forecasting of technological alternatives.

Apparently biotechnologies are offering alternatives that can avoid some of the pitfalls of current technology. Also it seems that developing countries can be in a position to develop and apply some innovations in this field in a relatively short term, thus paving the road towards a more autonomous technological pattern. Obviously one requisite for this is the strenghtening of agricultural R&D institutions in developing countries.

All together these reflections suggest that agriculture is acquiring a more prominent role in economic analysis and policy making, which is in itself an extremely important fact since it brings theoretical and analytical thinking near to the reality of developing countries.

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