Present and future trends in fruit research *

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I am both honoured and very pleased to address this distinguished assembly that has gathered here to celebrate the 50th Anniversary of the Aula Dei Station. Permit me briefly to recall that the links between my Department (DCA) and the Station go back a long way - about thirty years- and for myself and my colleagues in Bologna the Departament of Pomology of Aula Dei, under its Director Professor J. Herrero, was long regarded (before the advent of INIA) as the reference point for developments in Spain's fruit science and research. It is therefore with the enthusiasm of an old friend as much as that of a colleague of long standing that I warmly congratulate you on your achievements, past and present, and extend my warmest wishes for your continued success in the future. Let us now take a look together at research and its prospects in the fruit industry.

The significant changes currently taking place in Europe's fruit industry cannot but affect research and development programmes. The key issues at stake are familiar and need only a brief run-down (Fig. 1): (I) over-extension in acreage of the main fruit species throughout the EU, specially in the southern member states, but also in areas that have recently come under irrigation; (II) the ensuing surplus of supply has not been offset by an increase either in consumer demand or in exports and is being buttressed by increased yields per hectare, as for example in apple where yields have risen from 25 to 50 and, in some cases, even to 70 tonnes per hectare in new plantations; (III) these structural imbalances have not been offset by a parallel increase in fruit quality, and the lack of uniform quality standards has resulted in a wide range of fruit types that have heightened international market competition; (IV) these issues are further complicated by growing consumer concerns about ecology, the health value of produce, and integrated (IPF) and organic production techniques, while at the same time public opinion has been deliberately biased by certain mass-media campaigns against the alleged abuses of chemicals in agriculture and their environmental impact; (V) growers must change strategy to survive in the marketplace and ensure returns on their farm investments: the income of peach, apple, citrus and grape growers in certain areas has greatly reduced, despite EU intervention, investment capital no longer exists, farms and farmers are declining in number, certain crops are being replaced by others, and grower associations can no longer cope with this situation. The entire industry and its system of production are thus in need of an overhaul and restructuring, especially in areas where small holdings prevail.

How can European research efforts help to deal with these problems? Are current policy tools up to present and future tasks? Are the issues facing research in the fruit industry the same in all EU-member states?

RESEARCH POLICY

The differing situations currently found in the EU countries have led to the development of research strategies that differ from country to country. For example, the northern countries are adopting strategy options whereby the growers themselves foot part of the bill for research. If prospects for a return to industry from research investments are not deemed good, projects and funding are cut and personnel are forced to leave their jobs. The UK is a prime case in point, where the number of research stations has

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been reduced and others merged. The Netherlands is another, where each grower must pay a surcharge of about US $70 per hectare for fruit research: part of the Wilhelminadorp Station's budget is funded in this way.

The southern member states (excluding France) on the other hand are undergoing a "regionalisation" of research facilities, projects, personnel and funding. This strategy is designed to support research that is tailored to the needs of local growers, although the latter are not involved in financing the projects. This strategy, however, also entails higher costs in human and financial resources and less chance of successfully developing large-scale research programmes. One of the main advantages of this strategy is the enhancement of extension services, especially to underdeveloped and new areas that normally would not benefit directly from research. This approach has led in countries like Spain and Italy to a proliferation of regional and local stations and even to university seats, as for example in Italy where the number of agricultural science faculties has increased from 12 to 21 over the last 15 years. Needless to say, the main risk is the impoverishment of quality in the research being conducted. This situation is contrasted by that in countries like Germany, The Netherlands and France, where the number of faculties is far lower and the emphasis is on specialisation at both the university and other stations. This underscores the role of the EU, which has been financing research programmes that are at once international, interdisciplinary, collegial and multiannual, each involving 5-10 institutions and private industry, and that are based on co-financing arrangements.

The overall EU experience is thus gradually reducing differences between members, even to the point that nationalistic impulses in research are diminishing more and more as each country strives harder to bridge eventual gaps in particular fields with respect to other members. For instance, Spain is today the prime EU project manager in such important fruit research programmes as plant nutrition, gene mapping of *Prunus* species and ethylene in fruit ripening, to name only the most visible ones. The EU is thus changing the mentality of its single members in a very positive way. This can also be seen in the growing number of applications for project approval, although at the moment less than 15-20% of the projects submitted each year receive approval and financing.

This approach has also enabled certain northern members, with a strong research record, to secure funds for their projects and thereby offset the drop in funding from their own countries. The reality of the situation is such, however, that the EU itself is now cutting back on support. The EU's "green" budget is actually declining, both in real terms and as a percentage of total budgetary appropriations. This is also becoming a general policy line in all the member states, which are assigning fewer and fewer financial resources to agriculture. Still, a country like Italy continues to allot 40-45% of its "green" GDP (gross domestic product) to agriculture, including research. Fortunately, the new FAIR programme should give a needed and welcome boost to research over the next five years.

The situation in other countries is somewhat different. Japan, for instance, has enormously expanded its research potential in agriculture, including the fruit industry, by increasing local and national and private and public university faculties. Today it has about 50 agricultural science faculties (mostly private) throughout the country, and 700 permanent staff are directly involved in horticultural research alone. Needless to say, Japan is a wealthy country and very well aware of the strategic importance of agriculture.

RESEARCHER TRAINING

The quality of research depends mainly on the quality of the training that young researchers receive. One of the main requisites for a researcher today is that he or she must be able to change field, strategy, focus and goals with respect to the parallel and ongoing changes in technology, method, means and so on. Flexibility and convertibility are the key assets of both research and the professional reseacher. Education too must be able to help cope with these changes or risk falling behind. Thus the member states of the European Union must encourage greater uniformity of curricula and training among themselves. Still, certain discrepancies remain, especially as to whether the emphasis at universities is to be on specialisation or general knowledge. Italy and Spain still require far longer training periods for its qualified researchers than the Netherlands and the UK, where the masters and Ph.D. degrees are linked to advanced research and enable candidates to qualify earlier.

Another risk to high standards in research is the declining student population. This issue is felt in different ways by different countries. One way is the shrinking pool from which to choose prospective candidates. Another is that the university which imparts the training must itself be strongly research-oriented. The most advanced countries with the best reputation can offset the deficit in the student population by attracting the brightest foreign students to their institutions of higher education. For example, the undergraduate population in certain American universities has decreased dramatically while that at their post-graduate schools is stable or only slightly lower. A scientific education of high calibre is a necessary prerequisite to the training of quality research personnel. This is why the EU is promoting student mobility through exchange programmes like ERASMUS, TEMPUS and COMETT at the undergraduate level and the compulsory year abroad in a 'top-notch' institution at the graduate level. In addition, the EU's Mediterranean countries can provide an invaluable service to the advancement of agriculture in developing countries by hosting their students.

Strategies must be developed to ensure that the prospective researcher matures professionally year by year, keeps abreast of ongoing developments and trains his or her sights on the need to work for the common good, on the problems facing the potential beneficiaries of research and on the need to resolve them. Programmes must therefore be coordinated with extension services and their implementation approved by the governing bodies of the research institutions so that they meet the needs of growers. A corollary requisite to these strategies is an efficient system to disseminate and publish the results of research before they become out of date and useless.

RESEARCH INPUT-OUTPUT

Another facet of research that needs to be highlighted is the cost-benefit ratio, a concept that has taken on a different meaning from that of 10-15 years ago (Fig. 2). It was once enough to know that the effects or feedback of research increased economic rewards in terms of sales, turnover and profits. Today, although economic benefits are still important, they are not enough *per se* to secure funding of research projects. Indeed, if we look at the proposals submitted to the EU, or to the big national agencies, for approval and financing, the criteria employed to decide their value and worth have changed much. They now include (I) enhanced product quality in the broadest sense of the term; (II) the potential to increase consumption or strengthen export markets; (III) the capacity to generate social benefits, especially in marginal or economically underdeveloped areas, by creating jobs, as for example the development of small fruits in mountain areas; (IV) the enhancement of the quality of life for producers and consumers alike: fruit is not just a dietary or nutritional element but also a pleasure that establishes links between the consumer and nature; (V) the environmental benefits, whether direct or indirect, have become a priority concern in securing political approval: this means not just cleaning up environmental pollution but assuring that crops and their management techniques will not create imbalances in the agro-ecosystem; (VI) new technology as in biology, molecular engineering and so on: these techniques enhance the chances of project approval, at times even despite whether or not the goals are feasible and of importance; and (VII) political concerns carry far more weight today than before in the cost-benefit analysis of new projects: for example, in Italy it is very difficult to receive approval for projects headed by single researchers rather than for those developed under group efforts involving a number of institutions.

THE EVOLUTION OF RESEARCH

I have reached an age that permits me to call myself a witness to the world of research in the fruit industry. The last 50 years have seen a development in fruit science technology that has been not only dramatic but has far outpaced anything that has preceeded it over the last 2000 years (Fig. 3). The resulting economic, social and environmental impact has been just as extraordinary. Yet, despite these advances, the high returns on investment in fruit and other crops seem to be at an end. Although since the 1950s the labour demand per hectare has dropped from 2000 to 150 man-hours yearly, this advance alone is not sufficient to ensure that our technology can guarantee the economic success of a given farm or orchard holding in a market like Europe's today, where two dozen or so countries vie for the custom of consumers. Paradoxically, a smallholding is better able to survive in this competitive marketplace than a large farm that has an apparent edge in technology and cost-benefit ratio. For example, even in Japan very small orchards can survive successfully thanks to prices, which are 3-5 times higher than in Europe, and the fact that labour is not factored into the smallholder's costs.

I fear that the fruit industry, which is a warning light for agriculture in general, may be facing a future like the one depicted in a recent study by the Clinton administration of the U.S.A. It is, we may be on the threshold of an epoch in which science and technology will no longer develop at an unlimited pace. This means that research must train its sights on objectives other than those already mentioned and find new production equilibria and new modes of farm organisation and market distribution so as to keep a high quality of life for all. The result will be that people will earn relatively less. Suffice it to note that China and its farmers will want to be just like everyone else in 20 years. Incomes must therefore be safeguarded to ensure a quality future for the coming generations.

We witnessed during the 1950s and 1960s the enormous progress brought about by the mechanization of agriculture. The 1960s and 1970s then saw the advances brought about by chemicals in pest and disease control, nutrient inputs and so on. The 1970s and 1980s were the decades of genetics, the introduction of new genotypes better suited to given environments, higher yielding and higher in quality. The 1980s and 1990s have been and are marked by the realization of the dramatic effects caused by this technological spiraling, which far from cutting costs has triggered problems with the environment, health and the marketplace. These issues have brought about in Europe the gradual, and irreversible, rise of the concepts of *integrated fruit production* (IFP), whose philosophy has now been extended to all agricultural output. It would certainly not be out of place to note that this is almost a worldwide shift as it encompasses the concept of *sustainable agriculture* in the United States, which incorporates concepts inherent to IFP. Nor would it be amiss to say that even the more radical fringes in Germany and Switzerland that embrace organic farming and its direct offshoots can in the long view of things come under IFP. For IFP does not reject the principles of organic farming when these are supported by research and economics, although this type of verification still remains to be done for the most part in the organic fruit industry.

CURRENT RESEARCH TRENDS AND FUTURE OUTLOOK

The consequence of all these factors is that research in the fruit industry from the 1990s on must take account of IFP, its techniques and its goals. In the meantime, there has been a shift in the weight carried by new technology from mechanical engineering and even chemistry to the biological sciences, where the emphasis is on genetics and other applied biotechnologies designed to introduce new genotypes and cultivars resistant to biotic and environmental stresses.

Another feature that has come prominently to the fore is environmental physiology. It manipulates such natural resources as light, air, water, soil nutrients and so on, and employs computer-aided monitoring and other techniques to produce results which were unimaginable just a decade ago. All these advances must take into account fruit quality and diversification, which are the most important factors in gaining and retaining market share.

The events that today are delineating the profile research will take in the fruit industry over the coming decade fundamentally point not only to the need for renewal and new crop prospects discussed heretofore but also to the advanced technologies and services shaping its features. A brief summary of the key ones is a useful introduction to their discussion.

(I) *Genetics* is appropriating the advances in biotechnology that support breeding and appears on the verge of radically altering the traditional systems of crossing and selection. Cell and tissue culture, micropropagation, molecular markers and gene transfer are the most important of these techniques for fruit science.

(II) *Biology* is becoming more and more *applied physiology* in such areas as crop physiology, environmental or eco-physiology and reproductive morphophysiology (eg. incompatibility), all of which are closely linked to plant phenology and, especially, to *fruit quality*.

(III) Traditional orchard management is now split into *orchard* design (rootstock-scion-spacing-training system), tree/orchard efficiency (rootstock-canopy system control, nutrition-water supply interaction) and *orchard protection* (IFP is the key to research that is increasingly projected towards low-impact biological approaches).

(IV) *Monitoring and modelling systems* to control biological phenomena (eg. fruit and shoot growth, thinning, ripening), stresses, pests and diseases.

(V) *Postharvest handling and storage* through new biological and technical approaches to improve *fruit quality* and uniformity, shelf-life, transport, packaging, trademarks and labels, production guidelines and marketing.

(VI) *Analysis of economic and energy systems* their ripple or cluster effects on, and impact feedback from, innovations in, the environment, farm, family, society, marketplace, consumers.

(I) *Genetics and Breeding: New Biotechnologies*

Genetics has become the most important research tool in fruit science. It has engendered through breeding what can be called the *varietal revolution* and now, fuelled by the advances in the field of biotechnology and its related techniques, it is driving the efforts to develop new genotypes via asexual gene transfer. While traditional quantitative genetics is, of course, still very useful in trait segregation and seedling and parent selection, the aims of advanced breeding have changed. After decades in which the focus had been on the development of new cultivars designed to enhance crop yields and quality (colour, size, flesh texture) as well as to extend the ripening season at both the early and late ends, the emphasis today has shifted squarely to the recovery from old germplasm and resistant genotypes of all the traits linked to environmental adaptability, tolerance to salinity, drought and waterlogging, and resistance to the main pests, diseases (eg. fire-blight, scab, mildew, collar rot, crown gall) and physiological disorders (eg. split and bitter pit, water core, internal browning). All of this is taking place in an obviously changed context -that of IFP- in the more advanced countries.

The complete renewal or turnover in cultivars every ten-fifteen years, especially in peach and strawberry, that we have witnessed over the past few decades is what I have termed above the varietal revolution. Yet the pace of this breeding cannot continue to yield such successful cultivar harvests without introducing the new traits required by IFP. Apple is a case apart in this panorama because, though scab-resistant cultivars are available (over 100 to date), we still see the growing commercial success of cultivars that are not (eg. Jonagold, Fuji, Braeburn, Pink Lady, Golden Delicious, Red Delicious). These contradictions need to be bred out over the coming years. It is my personal view that if the new genotypes which are resistant to one or more diseases or pests do not have the advertising support of government in consumer-education campaigns, they are destined to remain largely unknown as consumers will continue to prefer the best conventional cultivars with good quality standards which are well known. It is my conviction that, in principle at least, a cultivar should be given market preference when, although its quality may be slightly below that of the conventional ones, it requires no chemical treatments and has very few, if any, residues in comparison to the former, which may be more eye-appealing but carries the risks of residues attendant upon the chemical treatments used in their management.

Yet it must be said that the development in the fruit industry of new cultivars through gene transfer is not around the corner, although in theory this technique has the great advantage of leaving intact the genome of the conventional varieties since it introduces only the desired gene. A limiting factor of gene transfer in woody species is the technique's low response rate. For example, the strains used for transfer via *Agrobacterium* sp. do not always evidence the necessary virulence, at least in grapevine and pear. It is thus necessary to find more suitable strains or techniques to strengthen the capacity of the ones now being employed.

One successful example we have to date is that of Dandekar and McGranahan at UC Davis, California, who have successfully introduced the toxic protein gene of *Bacillus thuringiensis* against codling moth (*Carpocapsa pomonella*) in walnut and apple, although trait expression and stability await confirmation. Direct gene transfer techniques have also been applied successfully to protoplasts of *Citrus jambhiri*, a relatively maleable species in vitro. Particle gun methods, which have been used on poplar hybrids, and *Vaccinium macrocarpon*, appear to be promising, especially when applied to tissues of high regenerative capacity like of meristems and embryos. Other examples are resistance to *Erwinia amylovora* in apple rootstocks by Aldwinckle and Norelli in Geneva, New York, which is still in the experimental stage, and the very promising mRNA antisense that extends apple ripening by inhibiting the ACC oxidase enzymes in the ethylene biosynthesis pathway. Thus, while in tomato a commercial product is already on the market ('Flvr-Svr'), there is

Figure 1.- Some of the key factors underlying the problems of Europe's fruit industry *today*

FRUIT INDUSTRY IN EUROPE TODAY

Key factors

- Acreage over-extension (South)
- Increased yield/ha
- Fresh fruit surplus outpacing consumption & exports
- Challenge of processed products
- Quality deficiencies = low market competitiveness
- Less EU market protection
- Industry survival: farming & research, management
- Near future: EU & Zaragoza fruit industry: "¡ Siempre Heroica!"

Figure 2.- Limited resources and health and environmental issues require targeted decision-making approaches in evaluating new research projects.

RESEARCH INPUT-OUPUT

- *Cost-benefit ratio*
- *New parameters in evaluating research projects:*
  - ◊- Enhance fruit quality
  - ◊- Promote consumption & market expansion
  - ◊- Social benefits
  - ◊- Enhance quality of life
  - ◊- Environmental benefits
  - ◊- Apply new technology (molecular biology, etc.)
  - ◊- Political concerns

none yet in the fruit industry. Biotechnology is a growth industry in agricul-ture but its impact has yet to be felt in fruit growing.

Cell manipulation and tissue culture. Work is under way to change plant metabolism so as to alter the quantitative ratio of the end product's components or to activate pathways that lead to the synthesis of new metabolites.

Unlike the most commonly employed *in vitro* techniques, suspension cultures offer greater potential in applications both for micropropagation and breeding. Cultured cells are in effect uniform but strains can be generated in them and selected without induction treatments. Mass production of somatic embryos cultured in suspension have been successful in carrot, the main model plant. Cell suspensions and regeneration techniques should also benefit fruit-tree species. Research in pear and apple has focused primarily on ripening and senescence (ethylene synthesis) using flesh explants. The formation and identification of several secondary metabolites belonging to the anthocyanin group have been extensively studied in grapevine. Similar work has been initiated in several *Prunus* species, whereas strawberry has been used to study the production of aromas via the addition of precursors to the media. The induction of regeneration in suspension cultures has been attempted in *Prunus*, *Vitis*, *Fragaria* and *Actinidia*. Somatic embryogenesis has been successful in grapevine and for purposes of propagation and to induce somaclonal or gene-transfer variability. Yet the difficulties with regeneration limit the use of cell culture techniques in creating variability.

Of interest too is the development of methods of somatic embryogenesis to improve selection techniques based on somaclonal variation and vegetative propagation for rootstocks and cultivars that are widely used or difficult to clone. The changes held to be particularly important are the resistances to biotic (eg. with phytotoxins) and abiotic stresses like water deficit, temperature and heavy metals, which can be assayed *in vitro.*

Plant regeneration from protoplasts has been successful in apple, pear and *Prunus* spp. The regeneration of somatic hybrids is possible by fusing wild-pear protoplasts with those taken from suspended cells of the Colt cherry rootstock. Organogenesis from somatic tissues is known for a number of woody species. Yet, given the multi-cellular origin of the primordia, the genetic uniformity of the regenerates cannot be assured. Regeneration via somatic embryogenesis is possible in a number of species because it ensures the unicellular origin of the regenerates.

(II) *Biology, Applied Physiology and Fruit Quality*

The biology of reproduction has always been important in fruit trees since few species are fully self-fertile and many have gametophytic self-incompatibility and, rarely, sporophytic incompatibility. Many studies being conducted in these areas today employ cytology, ultrastructural and SEM microscopy and biochemical electrophoresis for protein determination (eg. cell-cell recognition mechanism). Other important issues include pollination and the effects of air-borne pollutants and pesticides on pollen and on gametic cells: many groups are actively involved in this research and we can expect important results from this work as to the enhancement of plant fertility and yield as well as to the reduction of external energy inputs and field practices. These efforts are linked to studies on bud differentiation, dormancy, and the control of anthesis and fruit morphogenesis, which are of particular importance for protected fruit crops and in extending the harvest calendar.

An even more extensive field of research is environmental and crop physiology. Studies of the interrelations of micro-climate (light, temperature, gas exchange) and the individual leaves, organs and the entire plant itself are very topical. They are designed to provide direct insights into photosynthesis, respiration and transpiration as well as to modify and improve management practices and the yield efficiency of both the plant and the entire orchard. There are today instruments which can be used directly in the field for this research and which have the same precision and greater simplicity for its user than those that are routinely employed in the laboratory (eg. infra-red analyser). The DCA has designed and developed a unique system that combines computer technology and a plastic baloon-like field chamber to assay whole-plant gas exchange (Corelli and Magnanini).

There is also a wide range of modern instruments available for studies involving plant water stress (eg. energy-activated chlorophyll fluorescence) and supply (water potential measurements) and soil water availability. Another important topic in this area is the role played by the dynamics of stomatal opening and closing

Figure 3.- Main technological advances by decade in the fruit industry over the last fifty years.

MAIN FIELDS OF FRUIT RESEARCH IN THE LAST 50 YEARS

- **1940-90 Man-hours decrease from 2-3000 to 150-300 hrs/ha/yr.**
- **1950-60: Orchard mechanization**
- **1960-70: Chemicals:**
  - **- pest/disease control**
  - **- fertilization**
  - **- Equipment spray & picking:**
    - **water supply**
    - **cold storage**
- **1970-80: Breeding new cultivars**
  - **Irrigation & nutrition**
  - **Integrated pest management**
- **1980-90: Technological progress**
  - **a) integrated & biological pest & disease management**
  - **b) genetics-breeding molecular biology**
  - **c) crop physiology**
  - **d) micropropagation/breeding**
  - **e) controlled-atmosphere storage**
  - **f) information technology**
- **1990-2000: IFP - Integrated Fruit Production**
  - **- Biotechnology:**
    - **Genetics**
    - **Breeding**
    - **Gene manipulation**
  - **- Beneficial organisms**
  - **- Biopesticides & alternative pest control**
  - **- Orchard efficiency techniques**
  - **- Environmental physiology**
  - **- Soil management**
  - **- Fertigation**
  - **- Advances in post-harvest storage**

in determining a plant's water use efficiency. The different fruit species defend themselves against drought by this mechanism, so that the plant itself can continue photosynthesizing without losing too much water by transpiration. Species like kiwifruit lack this stomatal control and are more susceptible to water deficit. Shading can produce photosynthetic stress that results in fruit drop.

Today studies linked to phenology make it possible to investigate the physiological effects of many cultural factors, and apparatus like the image analyser and the rhizotron make possible studies that up to only a few years ago were unthinkable. The application of biochemistry, including enzymology, enable us to study the plant's metabolic processes, the biosynthetic pathways of the growth hormone compounds and nutrients that determine the development of roots, shoots and fruits. Much attention is also being given to the synthesis, storage and partitioning of carbohydrates.

Investigations of fruit morphogenesis and its relation to product quality has become a priority over many other studies in that each genotype must be induced to perform to the highest quality standards possible. Studies of fruit set and load, growth and maturation, senescence and abscission are still very important in the industry. All of these studies are linked to research in both fruit and grape concerning the interaction of maturation and fruit quality, the aim being to determine for each cultivar the cultural and management conditions needed to achieve optimum inherent taste qualities. Fruit physiology and metabolic chemistry are studied by the needs of commercial interests and postharvest handling and storage and do not ensure produce quality enhancement.

(III) *Traditional orchard Management*

The issues discussed heterofore are not meant to imply that research in such areas of traditional orchard management as plantation establishment, planting density, rootstocks, training systems, pruning, plantation efficiency, fruit quality and cost-benefit ratio are no longer important. These topics are indeed important because the modern orchard's life-span is short, return on investment must be rapid and overhead must be kept within economic limits. As a result, trees must be small and manageable wherever possible from the ground, as many operations are mechanised. Also, canopies must have optimum ground coverage to offset in expansion what they have lost in height. This means high density plantings, intensive management and specialization, i.e. concepts that can contrast, if applied too rigidly, to the principles governing a well balanced agro-ecosystem and IFP. Being a successful orchardman today thus requires a great deal of skill and, above all, intelligence.

The availability of many rootstocks and cultivars today enables growers to make sound and targeted decisions before establishing an orchard so as to prevent over-exploitation of the soil and waste of water and energy inputs. The ideal would be to plant a fully grass-mulched orchard featuring small trees that is both in harmony with the environment and able to sustain itself by fully exploiting the energy resources of the atmosphere and soil without impoverishing the latter and polluting the water table.

(IV) *Monitoring and modelling systems*

By virtue of the great advances in modern technology, monitoring and modelling systems have had an enormous impact on the way we investigate various plant phenomena. We can now take lengthy data sets for climate and phenology (development dates for shoots, roots and fruits) and construct models even in relation to the management factors conditioning these phenomena. Studies of the entire soil-root-canopy-atmosphere system are conducted this way, as are investigations that break down these phenomena into closely related cluster sets like fruit growth, source-sink competition of fruit,shoots and other centres of resource mobilisation and then relate them to ripening and fruit quality.

Modelling has also made it possible to forecast well in advance over the various seasons ripening dates and yields. Indeed, the results have been so good that each year analysts use the data to evaluate market trends. Yet perhaps the most important aspect of models for fruit scientists is their use in determining which factors in field management can be manipulated over a given season to enhance crop quality. This is what we are doing in apple at the DCA: the strategy is designed not only to forecast fruit yield, size and harvest date but also to establish via an expo-linear mathematical model when to apply fruit thinning, summer pruning, bioregulators and so on and how to modify the model's growth curve so as to determine the desired fruit size and quality.

(V) *Postharvest handling and storage*

Pre- and postharvest physiology is a very important branch of fruit science. Suffice to note in this respect that the handling, storage, and diseases to which the fruit is exposed during postharvest account for an overall crop value loss of 20-30% every year in the industrially advanced countries. The DCA, for example, is studying ethylene biosynthesis in relation to fruit quality and harvest date. We have designed and developed for this purpose a continuous-mode, computerised, automatic multisample analyser of ethylene, CO_2 and O_2 exchanges in fruits (Magnanini, Ventura, Sansavini).

(VI) *Analysis of economic and energy systems*

This brings us to the economic and energy analysis of the orchard. Today it is no longer sufficient to come up with trial data that are limited to yield. We must now strive for parameters that encompass crop quality and its potential market competitiveness. Indeed, the study of one particular phenomenon no longer exempts us from taking into account at the proper time and place the overall performance of the orchard itself and the impact that the given crop and its management have on the environment the farm and the surrounding area. An analysis of the entire system must employ econometric models so as to focus attention on and take into account all the types of costs and the various categories of input (energy, production means and services, whether in-farm or of outside supply). Here the objective is not to achieve a closed-circuit organic farming operation but one that is an integrated production system capable of including even small- and medium-sized holdings, like the ones in Spain and Italy, which are supported by both public (extension and contract services) and private (eg. cooperatives) facilities to sustain economically and socially their vitality.

Now that we have come to the end of this brief survey I wonder whether the fruit industry can renew itself and achieve the objectives that we have outlined here without asking itself, first and foremost, how to sustain and nurture a research system that is at once modern, coordinated, efficient and even integrated among the various EU member states.