Nuclear techniques and sustainable agricultural development

The IAEA's Seibersdorf Laboratories are contributing to the transfer of practical and environmentally friendlier technologies

by Pier Roberto Danesi

During the last few years, the words "sustainable development" have been written so often that they sometimes have become little more than a catch-phrase for labelling, without further elaboration, several new developmental initiatives. One purpose often has been to make new technological projects more palatable and easier-to-sell in so far as they claim to promote material growth while at the same time being "environmentally friendly".

Some words of clarification may be useful.

Sustainable development, as defined by the World Commission on Environment and Development (the Brundtland Report), is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Nevertheless, as pointed out by some observers, this definition is not new, and is somehow unclear, ambiguous, and quite incomplete. It has been emphasized, for example, that the adjective "sustainable" does not mean "sustained" and that the noun "development" does not necessarily imply "economic growth" on a global scale. Moreover, it has been pointed out that the use of the expression "sustainable growth" is a contradiction in terms since "sustainable refers to limits whereas growth means physical increase".*

Despite such criticism — much of it based on the Malthusian theory which holds that land and natural resources limit both the growth of economics and populations — the idea of "sustainable development" implying an unlimited growth in consumption has had much popular appeal. One reason for the appeal may have derived from the observation that recent experience has questioned the Malthusian theory by suggesting that a more efficient use of scarce resources and the development of cheap substitutes is possible.

Economic growth, however, has occurred at the expense of a continuous degradation of our environmental resources, to the point that the ecological life support system of the earth is being seriously threatened. Thus, a basic difference appears to exist between land and resources used as raw materials in production, on the one hand, and environmental resources, on the other, with respect to responding to market forces. Most environmental resources, such as air and water, are in fact mainly treated as unmarketed goods. Additionally, global environmental regulatory policies seem very difficult to implement. Within this context, optimism in scientific and technological approaches—which appear to be somewhat limited in being able to find solutions to problems—seems less justified.

The challenge of a development strategy that integrates conservation and growth, satisfies basic human needs, and maintains ecological integrity is formidable. Demographic predictions indicate that the world population, today equal to about 5.3 billion, may level out to more than 10 billion people over the next century. More than 90% of this growth will occur in nations where the average *per capita* income is about one-tenth of industrialized countries. This means that if the developing world—which is least able to cope with the resources and environmental consequences of an exploding population—is to achieve just one-third of the *per capita* income level of the developed countries, the world economy must expand more than thirty

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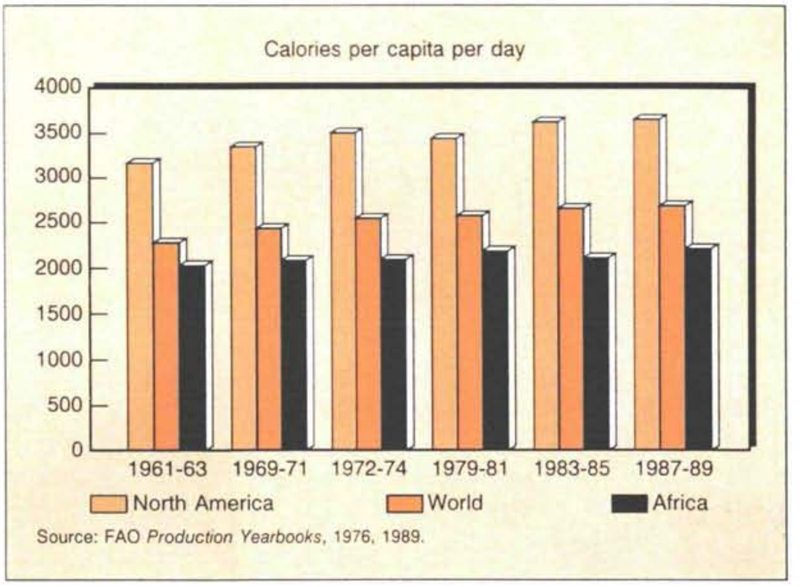
*See D Brooks' critical comment in the *IAALD Quarterly Bulletin* XXXVI, 4, (1991). The Brundtland Commission Report was published as *Our Common Future, Report of the World Commission on Environment and Development*, Oxford University Press, Oxford (1987).

times during the next 100 years. The immensity of this challenge is clearly sensed when viewed against the requirements set by the Brundtland report, namely:

- the environment and its natural resources have to be recognized as the basic foundation of all human activities and their satisfactory protection as a precondition for development.
- the flow of substances from the raw material stage through processing and production and on to consumption and waste should be as much as possible cyclic, and
- the production and consumption of energy should be rationalized.

This brief descriptive overview may help to place the role of technology—and particularly the role of nuclear techniques and applications—into clearer perspective. The role they play in "sustainable development" can be seen as a contribution to a multi-faceted effort. This effort seeks to offset as much as possible the limitations of our environment in accepting growth in those parts of the world where this is possible and necessary, and at least in improving the quality of life where consumption of material goods and energy is at far higher levels.

This article highlights the contribution to sustainable agriculture development of various nuclear techniques and methods developed and promoted by the IAEA's Laboratories at Seibersdorf and Vienna. A follow-up article, to be published in the next edition of the *IAEA Bulletin*, will highlight the role of the Laboratories in various other areas of sustainable environmental development.

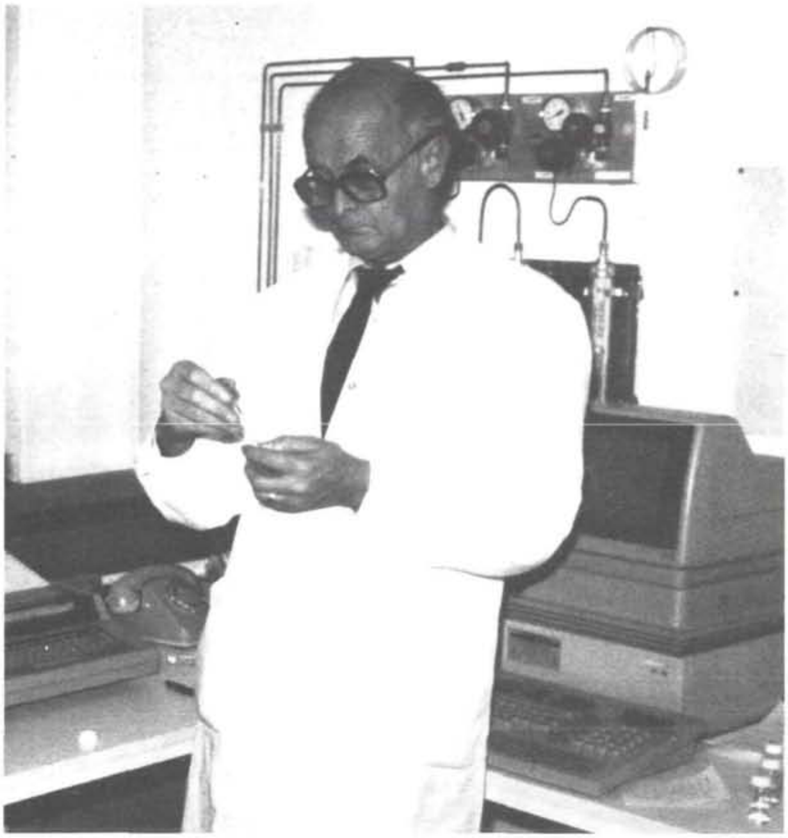


Food availability around the world

Overview of activities

The IAEA's Laboratories support many programmes at the experimental level in physical, chemical, earth, life, and agricultural sciences. In the agricultural sciences, significant contributions related to sustainable development are provided in soil fertility, irrigation and crop production, insect and pest control, plant breeding and genetics, and agrochemical and residues. The work includes, for example, research on the application of isotope techniques to minimize the use of nitrogen fertilizers, and studies on the application of a radiation-based technique to

A marketplace in India. (Credit: J. Marshall, IAEA)



Scientists analyse pesticide residues at the Seibersdorf Laboratories.

eradicate or control the population of insect pests through an approach that reduces the use of pesticides.

In general terms, the nuclear techniques and methods experimentally supported by the Laboratories can be grouped in one of the three following categories:

- ***Techniques for monitoring and assessing environmental pollution.*** These include analysis of non-radioactive and radioactive pollutants with nuclear analytical techniques; monitoring of pesticides residues in food and the environment; and climatic studies through isotopes in precipitations.
- ***Techniques for reducing the environmental impact of increased productivity.*** These include the sterile insect technique for insect pest control; studies of nitrogen fixation in crops and trees to optimize the use of fertilizer and to combat desertification; use of tracers for optimizing fertilizer use; and nuclear techniques for improving water management practices.
- ***Techniques for resource development.*** These include the use of isotopes for studying the origin and flow of water; and the use of radiation mutation for obtaining better crops.

In all fields of involvement, the Seibersdorf Laboratories contribute to the transfer of the selected techniques and technologies to national institutions, mostly located in developing nations. Essentially three approaches are used: training of scientists; provision of technical support and scientific services to IAEA technical co-operation projects; and research and development in support of IAEA co-ordinated research programmes.

Nuclear techniques in agriculture

Before addressing the Seibersdorf Laboratories' work concerning nuclear applications in agriculture, it might be useful to briefly look at key aspects of the world's agricultural development.

The production of grain—which provides about half of the world's calories—has increased from about 700 million metric tonnes in 1950 to over 1.8 billion metric tonnes in 1986, representing a growth of about 3% a year. Similarly, during the period 1965-86 the harvest of vegetables, pulses, and fruit grew by 2.5% a year. However, this impressive increase in production has been obtained, among other things, at the expense of a nine-fold increase in the use of chemical fertilizers and a 32-fold rise in pesticide application.

Although this agriculture production could in theory support about 6 billion people, when evenly distributed over the entire world population, it is not foreseeable that the huge disparities in both production and consumption will drastically change in the next decade. On the average, people in the richest countries, containing about 20% of the world's population, today eat 30-40% more calories than they need. Those in the poorest countries, on the other hand, get an average of 10% less than the basic minimum, and over 1 billion people do not get enough food to lead fully productive lives.

Moreover, after four decades of growth, the global harvest has shown a tendency to level-off over the past 7 years. *Per-capita* grain production was 345 kg in 1984, and fell to 296 kg in 1988. This decline, which appears particularly ominous when viewed against the rapidly increasing population, has been attributed partly to the steady and continuing degradation of agricultural land, its overuse and nutrient depletion, soil erosion, and desertification.

Every year the world's farmers lose about 24 billion metric tonnes of topsoil, corresponding to the amount that covers the entire Australian wheatlands. The Food and Agriculture Organization (FAO) has estimated that by the year 2000 soil degradation will take 65% of all the Third World's rainfed land out of production. In addition, each year 1.5 million hectares of irrigated fields are lost to salination. Against these figures, it has to be considered that arid and semi-arid regions comprise almost 40% of the world's land area having about 700 million inhabitants. About 60% of these arid and semi-arid regions are located in developing countries.

The seriousness of the situation can be appreciated by citing two examples concerning the Near East and India. In the Near East, about 75% of the crops are grown under dryland or rainfed conditions, and it is estimated that more than 70% of the projected food and feed deficit expected by the year 2000 can only arise from increased yields on established croplands. A similar situation exists in India, where 45% of the total crop production also comes from drylands. Here, production must increase by 60% by the year 2000 if adequate food and fiber is to be provided to an expected population of one billion people.

Although much of the recent leaps in agricultural productivity can be attributed directly to the increased use of agrochemicals and irrigation water, the drawbacks are that marginal land and water resources have been overused and environmental pollution, due to excessive use of pesticides and fertilizers, has dramatically increased. Therefore the excessive use of agrochemicals cannot continue to form the basis of increased food production. Nevertheless, it is unrealistic to believe that food demands can be met by avoiding their use: the world's population will approach 6.3 billion by the year 2000 while the agricultural area *per capita* is expected to decrease from $3000 m^2$ to $2000 m^2$.

What we can strive for is a judicious integration of chemical usage in the framework of sustainable development, where production is kept at a level commensurate with the requirements of the population. Particularly critical in devising sustainable agricultural systems then will be the availability of improved crop varieties, sound soil and water management practices to stop or preferably reverse desertification, and the judicious use of fertilizers and pesticides.

The agricultural activities carried out at the Seibersdorf Laboratories in support of the joint FAO/IAEA programme for food and agriculture deal with many topics which are related to more sustainable agricultural practices. The following sections offer an overview of work being done.

Soil fertility, irrigation, & crop production

Radioactive and stable isotopes are utilized to detect, measure, or track the fate of fertilizer applied to soil, the availability of nutrients from soil, and their use in plants. Nuclear techniques also have been used to determine the availability of soil moisture, while stable isotopes have been employed to measure and thereby improve the natural process of nitrogen fixation.

A scientist at the Seibersdorf Laboratories studies Azolla, a water fern that can serve as biofertilizer in rice paddies.

The problems inherent in cropping intensification and the increased pressure for limited agricultural and forestry land resources are being addressed. It has become clear that nitrogen is a critical element in meeting the global needs for food, feed, fuel, and fibre in the immediate future. Consequently, inputs of nitrogen fertilizer are often necessary to obtain desired levels of plant production.

However, studies have shown that only a fraction of the fertilizer applied to the soil is taken up by the crop and that increasing amounts of native soil nitrogen and applied fertilizer nitrogen find their way into the environment as pollutants, depending on the fertilizer practices adopted. The entry of nitrogen compounds into ground and surface waters pollutes drinking water and causes eutrophication of inland water bodies. Other adverse environmental effects are created by the release of gaseous nitrogen compounds through chemical and microbiological processes such as ammonia volatilization, formation of nitrogen oxides, and denitrification. These problems demand that fertilizers, in particular nitrogenous fertilizers, are used efficiently for plant production, i.e. with minimal environmental impact.

The stable isotope nitrogen-15 has provided a very powerful tool for quantitatively studying the behaviour and transformations of nitrogen fertilizer in the environment and the fate of its residues in agro-ecological systems. The Seibersdorf Laboratories have played a key role in the implementation of co-ordinated research programmes on the efficient use of fertilizer in grain food crops by developing appropriate isotope techniques, providing analytical services, and transferring this technology through scientific training.

The adoption of improved fertilizer practices results in less fertilizer being used for producing the same amount of food. In many countries, this has translated into savings worth many millions of dollars each year and in less loading of nitrogen into the environment.

In the field of soil science, the Laboratories also are conducting research in two complementary areas: determining the best fertilizer management practices, e.g. the timing, placement, and source of fertilizer; and identifying plant genotypes that are efficient in nutrient uptake and use, i.e. give the same yield with lower fertilizer inputs into the soil.

Nitrogen-15 techniques also have been demonstrated to be an essential aid to monitoring changes in available soil nitrogen and for measuring denitrification losses and biological nitrogen fixation under field conditions.

The nitrogen-15 methodology for quantifying the amount of biologically fixed nitrogen in field-grown grain legumes was largely developed at the Seibersdorf Laboratories. It has been subsequently adapted to other nitrogen fixing systems. Current research activities are aimed at maximizing the use of this alternative supplementary nitrogen source in several agricultural systems, including agroforestry. Those plants which can fix nitrogen utilize the abundant nitrogen gas present in the atmosphere in a process indirectly powered by solar energy. The process is environmentally safer and does not involve the pollution hazards associated with the indiscriminate use of chemical fertilizer.

Nitrogen-fixing trees are recognized to be capable of playing a significant role in sustainable agricultural practices of peasant farmers in the developing world. These trees, apart from being sources of fuel wood, animal feed, paper pulp, forage, and timber, also contribute to the restoration and/or maintenance of soil fertility. To utilize this natural and inexpensive source of nitrogen, reliable estimates are required of the biological nitrogen fixing capabilities of trees adapted to particular agroecological conditions. To this end isotopic techniques are used in the Laboratories to quantify the nitrogen fixed by some nitrogen fixing trees (for example, *Gliciridia, Leucaena, Acacia,* and *Casuarina*) commonly used in agroforestry systems and also to study factors which influence the nitrogen fixation process. In the future it is planned to use isotope techniques for studying nutrient (especially nitrogen and phosphorus) cycling in specific agroforestry systems.

Agrochemicals and residues

Studies aided by the use of radioactive tracers are done to follow the fate of agrochemicals and their residues. The objective is to develop more effective utilization of pesticides and to minimize or eliminate undesirable side-effects. Radiolabelled compounds also are used in the development of controlled-release formulations of pesticides.

The research and development activities carried out in this field at the Laboratories are consistent with the concept of sustainable agriculture, since they are oriented towards a more efficient and safer use of pesticides. For example, controlled-release formulations of pesticides may result in a reduction of the quantity of pesticides used, improved safety for the applicator and other non-target organisms, less environmental contamination (including ground water contamination) and more efficient and economical pest control.

Exemplary is work on the use of insecticide-impregnated targets for tsetse fly control. The aim here is to reduce or eliminate the old spray approach using pesticides indiscriminately. The selective placement of insecticide-impregnated targets, and the possibility of their retrieval and proper disposal after use, makes this technique non-contaminating to the environment and safer to the ecosystem in general. The Laboratories also are studying potentially adverse effects of organochlorine pesticides on African flora and fauna.

Insect pest control

Insecticides are the primary method of controlling insects and will remain so in the foreseeable future. However, these chemicals continue to cause environmental concerns and insects continue to become resistant to them. Moreover, the very high cost of developing new insecticides, resulting from acknowledgement that these chemicals may pose health problems and the need to evaluate their environmental fate and behaviour, is a limiting factor in the development of new insecticides. These factors have led to increased research for alternative methods of controlling insects. One of these methods is the Sterile Insect Technique (SIT), a genetic method of insect pest control based on the birth control of insects.

Emphasis at the Seibersdorf Laboratories in the area of insect and pest control is on the SIT. This technique, one of the most target specific and environmentally friendly means of pest insect control, is based on the production and release of insects that have been sexually sterilized by gamma radiation. When the released sterile males mate with their wild female counterparts, no progeny is produced. By repeated releases of sufficient numbers of sterile males, a pest population can be eradicated. Since the technique is target specific, no other living organisms in the release area are affected. This is why the SIT is environmentally friendly. Because the economic benefits from eliminating the pest problem accumulate with time, the SIT can be tremendously profitable. Research conducted in the Laboratories to improve procedures for mass rearing insects and to develop sterilization procedures has contributed to increased efficiency and efficacy of the SIT for the control of the Mediterranean fruit fly (Medfly) and tsetse flies. Efforts are under way to develop rearing methods for other insect pests with the aim of applying the SIT for their control.

In most SIT programmes, both sterile males and sterile females are released since the sexes cannot be easily separated. When only sterile males are released, there is usually an increased efficiency of the sterile males since there are no sterile sisters to compete with the native females. By eliminating females during the egg or young larval stage, cost savings can be realized in rearing. Research on genetic methods of separating insects by sex or producing only males for SIT programmes is also performed at the Laboratories. Recently, mutant strains of the Medfly have been created in which the females can be selectively killed during the rearing process simply by raising the temperature. In this way, only males are produced and released. Since males are the active component of a SIT programme, tremendous benefits and saving can be realized.

Efforts also are under way to develop insecticidal pathogens, which can be applied to reduce wild populations of insects targeted for eradication by the SIT. Reducing the wild populations before release of sterile males reduces the numbers released and the time required for achieving eradication. For this purpose strains of the bacterial entomopathogen, *Bacillus thuringiensis*, are being found and developed that are biocidal to the Mediterranean fruit fly. Efforts are made to find strains of the bacterium, which produce active agents that are target specific so that no other organisms in the environment will be harmed by their use. By combining use of bacterial pathogens with the SIT, integrated pest management systems are being developed that are target specific, economical, effective, and less harmful to the environment.

Plant breeding

The domestication of wild species made the first farming possible and selective plant breeding made them more productive. Later other factors assumed particular relevance as monocultures became more established. These concerned damage by pests and diseases and the response of plants to water and fertilizer input, as well as mechanical harvesting, processing, and storability.

Today the health of the world's harvest is very dependent on genetic resources. Only three species—wheat, rice and maize—provide half of the world's food. Another four—potato, barley, sweet potato, and cassava—bring the total to three quarters. Such a strong dependence on a few crops is dangerous. Disease can rapidly spread through monocultures, as happened with the Irish potato harvest in the 1840s that caused a fifth of the country's population to die. In the 1960s, an epidemic of the wheat disease, stripe rust, struck the United States and the state of Montana lost a third of its harvest. The situation was in this case saved thanks to the genes from a wild wheat from Turkey which provided resistance to this and 50 other diseases. Maize has also been very vulnerable to such disasters, since inbreeding has given it an almost uniform genetic background. Using the genes from two wild varieties, it has nevertheless been possible to confer resistance to seven diseases to the maize crop.

Although interbreeding with wild varieties may increase yields and protection from diseases, the use of artificially induced mutations has recently greatly helped to increase agricultural production. In the last 20 years (1970-90), the number of cultivars derived by induced mutations has increased from 117 to 1500. Of these, 90% were derived from radiation-induced mutations.

The new mutant varieties, all officially approved and tested, have been released in about 50 countries. In this way valuable new germplasm for cross-breeding has been made available to plant breeders, increasing the number of traits that farmers, processors, traders, and consumers need.

Over the past 50 years, several plant breeding programmes worldwide have made use of X-rays, gamma rays, and neutrons to induce mutations in plants. Desirable mutants are then selected from among the progeny of mutagen-treated plants.

The most important features which may be obtained by radiation mutagenesis in relation to a sustainable agricultural development are:

- an increase in disease resistance to decrease the use of chemicals against pests, thereby contributing to protection of the environment,
- improved agronomic characteristics, such as greater tolerance to poor soil conditions, drought, heat or winter hardiness, thereby enabling crops to adapt to marginal land,
- shorter maturing times to escape frost and pests and permit field rotation with other crops, improved lodging resistance (shorter height and stiffer stems) that give crops a better chance to withstand hard rain and storms,
- increased yield by improving, for instance, nitrogen fixation.

Scientists at the Seibersdorf Laboratories. (Credit: Katholitsky, IAEA)

Work at the Seibersdorf Laboratories in the field of plant breeding includes supporting projects for increasing the pest and disease resistance of tropical crops such as banana, plantain, cassava, yam, and cocoa by radiation induced mutations.

Worldwide the genetic resources for plant breeding have been increased by utilizing the methods of micropropagation combined with *in vitro* mutagenesis. New pest-resistant varieties have been created which should lead to a decreased dependance on pesticides. At the Seibersdorf Laboratories experimental work is being performed at creating resistance to *Fusarium* and Black Sigatoka in plantains and bananas. High-yielding mutant clones originating from the Seibersdorf Laboratories are now under field testing in Honduras, Egypt, and Australia.

Techniques of pollen mutagenesis and somatic embryogenesis also are being applied in cocoa for induction of virus resistant trees in Ghana.

Concerning cassava, an important crop in tropical countries, the Laboratories' work is focused on the optimization of mutation techniques in tissue culture and on providing material for field testing in Colombia. The objective is to obtain by *in vitro* mutagenesis a gene pool which permits the breeding of cassava for increased tolerance to environmental stress.

Radiation mutation breeding studies also have been conducted on the *Azolla-Anabaena* symbiotic water fern to enhance tolerance to abiotic stresses such as salinity, toxic aluminium levels, and the herbicide Propanil.™ The *Azolla-Anabaena* system is an important nitrogen fixing system which acts as biofertilizer to rice paddies. The clones, obtained by gamma irradiation at the Laboratories, were field-evaluated in the Philippines, China, and Thailand. They were found to have resistance to extremely high levels of salinity and to be capable of growth under high acidity and aluminium conditions.

The plant breeders of the Laboratories additionally are using new molecular biology methods for screening desirable mutants. For example, the technique of DNA fingerprinting in *Musa* is now used for characterizing the genomic DNA of the most important cultivars of plantains and bananas. The technique will facilitate the selection of the agronomically important traits of these tropical crops. ❐

The second article of this two-part series — to appear in the next edition of the ***IAEA Bulletin*** *— will focus on environmental areas of sustainable development.*