Applications of Isotopes and Radiation in Agriculture*

by C.G. Lamm

When people think of atomic energy they often have nuclear reactors in mind. Few, however, realize that another aspect of atomic energy has changed their daily lives during the last 20 or 30 years. When the International Atomic Energy Agency came into being in 1957, one of its major initial objectives was to promote the wider use of radioisotopes and radiation sources in research, industry, agriculture and medicine. Today few people are aware of the extent to which this objective has been achieved. For example, radioisotopes and controlled radiation are used to improve food crops, preserve food, determine groundwater resources, sterilize medical supplies, analyse hormones, X-ray pipelines, control industrial processes and study environmental pollution. A great many of the objects we use in our daily life have in some way benefited from radiation during their production.

Some radioactive elements, such as radium, are found in nature, but most radioactive materials are produced in nuclear reactors or by accelerators. Usually only one type of radioisotope can be produced at one time in an accelerator, in contrast to a reactor where many different radioisotopes can be produced at the same time.

With the advent of nuclear reactors, it became possible to make large amounts of radioactive material at low cost. This is why the use of artificially produced radioactive isotopes has become widespread since the late 1940's. Modern technology has also made it possible to employ stable isotopes, that do not emit radiation, within reach of the scientific community.

In our daily life we need food, water and good health. Today, isotopes have come to play an important role in the technologies that provide us with these basic needs.

FOOD AND AGRICULTURE

In 1964, the Food and Agriculture Organization of the United Nations (FAO) and the International Atomic Energy Agency (IAEA) set up a Joint Division of Atomic Energy in Food and Agriculture, which is housed at the IAEA headquarters in Vienna. This Joint FAO/IAEA Division supports and co-ordinates research projects throughout the world on the use of isotopes and radiation in the fields of plant breeding, soil fertility, irrigation and crop production, insect and pest control, livestock production and health, chemical residues and pollution and food preservation. The Agriculture Section of the IAEA Laboratory at Seibersdorf, outside Vienna, supports those efforts when needed in terms of training, research and services.

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The Joint FAO/IAEA Division has international programmes that seek to:

1. produce high yielding, high protein-containing varieties of food crops;
2. produce disease- and weather-resisting varieties (sometimes an early one, for two or more crops per year);
3. locate and make efficient use of water resources;
4. determine fertilizer uptake and the role of trace elements;
5. control or eliminate pests;
6. prevent losses of crops during storage;
7. improve productivity and health in domestic animals.

In all of these areas, isotopes and radiation techniques have made substantial contributions. The following highlights some of these programmes which all aim at strengthening national capabilities mainly in terms of training and expertise.

PLANT NUTRITION

The efficient use of fertilizer is of great importance because fertilizers are not only expensive, but for many countries they mean a great expenditure in foreign currency. The incorrect use of fertilizers is costly, and may damage the environment. It is therefore essential that a maximum amount of the applied fertilizer finds its way into the plant and that the minimum is lost due to poor placing, bad timing, etc.

Fertilizers labelled with radioactive isotopes such as phosphorus-32 or with stable isotopes such as nitrogen-15 provide a means of determining how much of the fertilizer is taken up by the plant and how much is lost to the environment. Nitrogen-15 also provides a direct assessment of the amount of nitrogen being fixed from the atmosphere under field conditions.

In one country that took part in a research programme on nitrogen fertilization of maize, which was organized by the Joint FAO/IAEA Division, it was estimated that the benefit to that country amounted to 36 million US dollars per year after its farmers had adopted the findings of the research programme for the most efficient placement of fertilizer. In a similar programme involving coconut palms in Sri Lanka, it was found that the efficient use of fertilizer not only yielded direct savings in the cost of fertilizer but also an estimated potential saving in production cost. Similar programmes on crops such as rice have yielded savings of millions of dollars in decreased fertilizer costs. Additional savings are possible. A group of experts recently estimated that up to 50 per cent of the fertilizer used at present in all countries could be saved by improved fertilizer, better water management and better cropping methods.

INSECT CONTROL

While some insects are important for maintaining the natural ecological balance, others destroy valuable food crops. Some insects such as the mosquito and tsetse fly are vectors of infectious diseases.

It has been estimated that, for the world as a whole, crop losses caused by insects may amount to as much as 10 per cent of the total harvest, an amount equal to the total harvest of a country such as the USA or the USSR.

Figure 1. Fertilizer labelled with the stable isotope nitrogen-15 enables researchers to determine the nutritional needs of crops and to increase the efficiency of fertilizer use.

Biological control methods have the advantage of being specific to the target insect and of helping protect the environment by minimizing the use of insecticides. It is here that the sterile insect technique (SIT) can help and in fact has done this already in some quite dramatic instances. SIT consists of giving sterilizing doses of ionizing radiation to laboratory-reared male insects. The sterilized males are then released in large numbers in infested areas. Females that mate with the sterilized males do not produce progeny, and with repeated releases of sterilized males in an area, the population of the insect pest is drastically reduced.

The first successful SIT application was made on the screw-worm fly, a troublesome pest that lives in the wounds of warm-bodied animals, particularly livestock. Male screw-worm flies were reared and sterilized by radiation and released on the Caribbean island of Curacao. Within a few breeding cycles, the pest virtually disappeared from this island. Later SIT was used to control the screw-worm fly in Florida, where cattle losses due to that fly had reached a figure of more than 25 million US dollars a year. Encouraged by these first successes, many research projects were sponsored and over two hundred species of insect have been studied.

A great research effort was made into the Mediterranean fruit fly, which proved to be another success in Capri and other islands Recently, an isolated pocket of Mediterranean fruit fly infestation was eradicated in California by first using insecticides followed by SIT and the method is now being used in Central America on a large scale with support from the Joint FAO/IAEA Division and its Laboratory. The melon fruit fly was similarly eradicated from the island of Rota in the South Pacific.

One of the greatest pests in the world is the tsetse fly, which is the vector of a parasite that causes sleeping sickness. The tsetse fly is a major obstacle to the socio-economic development of Africa south of the Sahara because the parasite infects both man and cattle.

In order to be able to use the SIT technique on the tsetse fly, the Joint FAO/IAEA Division first had to solve the problem of economically rearing large numbers of tsetse flies in the laboratory. The problem of monitoring the effectiveness of SIT in the field also presented a serious difficulty, but a simple technique based on microscopic examination of the reproductive system of females has been developed. Entomologists believe now that large-scale projects of tsetse fly eradication can begin in which SIT is integrated into the pest management scheme. In the Upper Volta region some successful test experiments have been carried out. A large project is being implemented in Tanga (Tanzania) and another is being undertaken in Nigeria.

MUTATION

During the last 15 years, radiation-induced genetic alterations have increasingly contributed to the improvement of crop plant varieties and mutation breeding has become an established part of plant breeding methods. About 200 varieties of crop plants developed by using induced mutations and an equal number of ornamental cultivars have been found valuable by the appropriate national authorities to be released and approved for commercial production. Many of these have become economically important.

An example of successful mutation plant breeding is the development in Hungary in co-operation with the IAEA Laboratory at Seibersdorf of a new rice variety that is resistant to blast, a very damaging rice disease. A French variety, Cesariot, known to have a good resistance to this disease and to other diseases too, was tested first. However, this variety was late maturing in Hungary, and in cool summers it would not produce good yields. Sometimes it would fail completely. The aim of the genetic changes desired in this case was clear. It was necessary to make mutations that would give early maturity, while retaining good blast resistance and other valuable characteristics. Samples of a thousand seeds of the Cesariot rice variety were irradiated with different amounts of gamma radiation and with fast neutrons. The irradiated seeds were planted, and selection for early flowering started in the second generation and continued in the third generation. It was observed that one of the mutants which resulted from fast neutron irradiation "headed" three weeks earlier than the mother variety. The seeds from this mutant rice were propagated. In subsequent generations, this mutant line showed very rapid germination and early growth, in fact 28 days earlier than Cesariot. Further experiments were carried out and this mutant proved to be satisfactory in variety trials with high and low level nitrogen fertilizer.

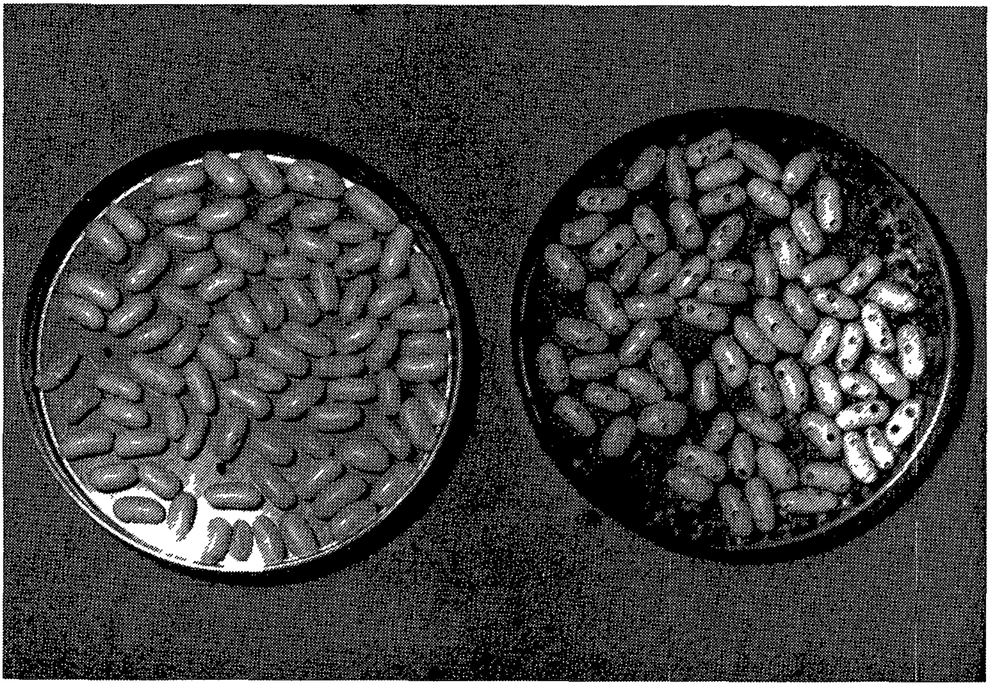

Figure 2. Infestation of white kidney beans by weevils can be virtually eliminated by low doses of gamma radiation.

Also, the tillering capacity proved to be very good. Thus, with a relatively simple mutation project, the immediate problem was solved. An early maturing, disease resistant line of rice mutant was developed that could be used directly and also is useful in further cross-breeding. This mutant was recommended officially as a new variety for commercial use in 1976 under the name of Nucleory-2A.

There are dozens of similar successful mutants in use in other countries, for example, high-yielding mutant barleys with short stiff straw which can utilize higher doses of fertilizer for increased grain production. In fact, today most of the spring barley acreage in Czechoslovakia and the German Democratic Republic is planted with radiation-induced mutants plus their descendants further improved by cross breeding.

Another example is the improved pearl millet hybrid grown in India over an area of several million hectares. Pearl millet production, which had risen to eight million tons during 1970, came down to 3.6 million tons during 1974, due to a severe attack of downy mildew disease, especially in the hybrids. The percentage of disease varied from 30 to 100 per cent in different areas.

The main reason for this failure was that the male sterile line of the pearl millet hybrids became so susceptible to disease that it was no longer possible to raise it. Efforts to induce disease resistance in this male line through irradiation resulted in the development of a line which showed a high degree of resistance to downy mildew. When the line was released, it became the only male sterile line suitable for hybrid seed production in India. The increased yield due to the new resistant hybrids should eventually be more than three million tons which would have a value of roughly 300 to 400 million US dollars a year.

FOOD PRESERVATION

In a hungry world, it is too great a luxury to lose 25 to 30 per cent of the harvested foods to spoilage by microbes and pests. What is even more regrettable is that these losses are largest in developing countries. Often an extension of shelf life of certain foods (i.e. fish and fruit) of a few days is enough to save them from spoiling.

More than 25 years have passed since radiation was found to be applicable to extend the shelf life of certain foods. Since then, great efforts have been made to test the wholesomeness of radiation-processed food In the 25 years of testing such foods, no harmful effects to animals or humans have been found. Some authorities, however, have been slow in recognizing this cheap and efficient food preservation method. Now the results obtained have become so convincing that the attitude of the relevant authorities is changing and some irradiated foods are being released for general consumption.

At least 70 research and pilot plants for food irradiation are in operation. The recent interest of governments in the application of food irradiation is demonstrated by the fact that most of the irradiators have been built during the last 5-10 years.

Economic analysis of food irradiation shows that it can have a favourable cost/benefit ratio. Depending on the size of operation (annual throughput capacity), the total operating costs for this new process varies from 0.9 to 3.2 per cent of the value of the product for sprout inhibition in potatoes and onions, from 0.19 to 1.24 per cent for grain disinfestation, and from 0.2 to 2.0 per cent for the prolongation of shelf life of fish.

The FAO/IAEA co-ordinates research in many countries, e.g. in Southeast Asia and the Far East, with the aim of extension of shelf life of dried fish — a most important protein food for the developing countries.

ANIMAL PRODUCTION AND HEALTH

In many regions of the world animal production is limited by poor growth, reproductive performance and milk output of livestock, which limits the availability of animal products such as meat, milk, eggs, fibres, leather, etc. for use by man. Reduced animal production results from inadequate or unbalanced nutrition, lack of adaptation to the prevailing climatic conditions, and parasitic and other diseases.

Co-ordinated research programmes on the study of non-protein nitrogen metabolism using N-15 and the utilization of low quality roughages and agro-industrial by-products in ruminants, together with studies on mineral imbalances, are helping to devise alternative feeding practices in countries where traditional feeds for ruminants are in short supply.

A programme in which radio-immunoassay techniques are used to measure the hormonal changes during the reproductive cycle of cattle and buffalo is leading to enhanced reproductive efficiency through better management practices and more efficient use of artificial breeding techniques.

Figure 3. Radiation-attenuated vaccine for sheep lungworm disease holds great potential for controlling the disease in developing countries.

A major limitation to increased production is that caused by parasitic and other diseases. Isotope techniques are not only providing a well-defined picture of the effect that parasites have on hosts but are also illustrating how management and genotypes (breeds and species) can be modified to reduce the effect of the parasite or disease on production. Ionizing radiation has been successfully used to produce an attenuated vaccine against lungworm in cattle and sheep and this technology is being transferred to those areas of the world where control of this parasitic disease is of economic importance, e.g. Brazil, India, Ethiopia.