Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Nuclear Technology serving Agriculture

The Joint FAO/IAEA Programme of
Nuclear Techniques in Food and Agriculture

FAO/IAEA Agriculture & Biotechnology Laboratory

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The FAO/IAEA Agriculture & Biotechnology Laboratory is part of the International Atomic Energy Agency's Laboratories at Seibersdorf, Austria. It plays a key role within the framework of the Joint FAO/IAEA Programme in supporting Member States on Nuclear Techniques in Food and Agriculture.

Laboratory priorities

The FAO/IAEA Agriculture & Biotechnology Laboratory is a multidisciplinary facility that develops and disseminates suitably adapted nuclear and related methods for studying and solving issues relevant to sustainable agricultural production in Member States. Its activities focus around three main pillars:

- Research and development to adapt agricultural technologies to suit local requirements and environmental conditions in support of Coordinated Research Projects (CRPs) and Technical Cooperation Projects (TCPs)
- Training, emphasizing the sustainable transfer of nuclear and related techniques
- Services, including the supply of materials and the provision of analytical and quality assurance services and expert support

To effectively meet this challenge, the Laboratory is organized into five Units, which function as counterparts to the respective Sections of the Joint FAO/IAEA Division in Vienna:

- Soil Science
- Plant Breeding
- Animal Production
- Entomology
- Agrochemicals

Fellowship training gives scientists from developing countries hands-on experience with nuclear and related techniques

Soil Science

The Soil Science Unit deals with nuclear techniques for measuring soil, water and plant processes important for crop production, and studies ways of manipulating these to optimize the use of plant nutrients. Examples include:

- Use of stable isotopes to measure nitrogen fertilizer use efficiency and biological nitrogen fixation, to select plant genotypes with superior traits for water uptake, and to study the dynamics of soil organic matter
- Emission and mass spectrometric analytical techniques for measuring stable isotopes nitrogen-15, carbon-13 and oxygen-18
- Phosphorus-32 and P-33 based methods for measuring phosphate fertilizer use efficiency, identifying local phosphorus resources and studying the fate of phosphorus in soil
- Caesium-137 based methods for studying soil erosion
- Neutron moisture probes and gamma gauges to measure soil/water balance and soil bulk density

Plant Breeding

In the Plant Breeding Unit induced mutations are used to improve food security and cash crops in Member States. Focus is on developing, adapting and disseminating appropriate methodologies for enhancing efficiency in the induction, detection and evaluation of mutation events using a range of biotechnological methods, including in vitro and molecular genetic techniques. This is being achieved through the structuring of the Unit's R&D activities according to a matrix of a 3-commodity model crops platform of rice, banana and cassava.
The current emphases target the bringing, in a concerted manner, of these techniques to bear upon:

- Developing saline tolerant rice varieties that thrive well on poor, salt-contaminated soils
- Developing bananas and plantains tolerant to black sigatoka disease, the single most important plantation disease of this crop
- Adding value to cassava through the development of mutants with desirable starch characteristics for target industries

In order to enhance the capacity of Member States in the use of these technologies, a range of services are provided to requestors, including:

- Induction of mutations in a large variety of food security and cash crops
- DNA fingerprinting of crop mutants
- Flow cytometry measurement for the determination of ploidy levels of plants, a prerequisite for genetic improvement involving hybridization across ploidy level
- Access to the Mutant Germplasm Repository (MGR), a registry and distribution system for plant breeders of mutants varieties

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Animal Production

The Animal Production Unit develops and standardizes immunoassay-based (RIA and ELISA) methods and reference reagents for monitoring reproductive hormones and diagnosing infectious diseases, and operates external quality assurance programmes. It is designated as the FAO/IAEA Central Laboratory for ELISA and Molecular Techniques in Animal Disease Diagnosis and supports the FAO EMPRES programme. It is also the Collaborating Centre for the World Organisation for Animal Health (OIE: Office International des Epizooties) for the application of ELISA and molecular techniques in the diagnosis of animal diseases. As such it supports the OIE Biological Standards Commission. Most diagnostic kits developed through the Unit have been internationally validated and standardized, enabling production and distribution to be contracted out to other institutes or commercial enterprises.

Examples of kits developed or adapted by the Unit for use in the FAO and IAEA Member States include:

- Progesterone
- Rinderpest and Peste des Petits Ruminants (PPR)
- Brucellosis
- Foot-and-mouth disease (FMD)
- Contagious bovine pleurophneumonia (CBPP)
- Trypanosomosis
- Newcastle disease.

The Unit is also involved in the development of new tools that will enable the differentiation between infected and vaccinated animals and that will improve efficiency of disease control / eradication programmes, including marker vaccines and companion ELISA test for PPR and FMD based on the use of the virus non-structural proteins. It also conducts R&D focused on the search for molecular genetic markers of economically important traits with the aim of providing improved tools for animal breeding programmes.

Entomology

The Entomology Unit focuses on improving the effectiveness and efficiency of the Sterile Insect Technique (SIT) for the integrated area-wide application against fruit flies, moths and tsetse flies, and develops technologies to assess the feasibility of using the SIT to control mosquitoes. Key activities involve mass rearing, mating behaviour, genetic sexing, genetic transformation, quality control, radiation sterilization and strain development. Current work includes:

- Improving mass rearing and quality control systems for *Anastrepha* and *Bactrocera* fruit fly species
- Assessing the potential of the use of genetic transformation technology for the development of genetic sexing strains and genetically marked strains
- Improving mass rearing efficiency of tsetse flies through automation, pupal sexing and virus management
- Developing systems for mass production, genetic sexing, radiation sterilization and quality control for mosquito vectors of disease
- Using field cage systems to evaluate the quality of sterile males

Agrochemicals

The Agrochemicals Unit, including the FAO/IAEA Training and Reference Centre for Control of Food and Pesticides (TRC), promotes a "farm to fork" approach to food safety through:

- Development and validation of methods for analyzing residues of agrochemicals such as pesticides and veterinary drugs, and contaminants such as mycotoxins, in food and environmental samples
- Use of isotopes for quality control during methods development to study the environmental behaviour and fate of pollutants in the environment
- Provision of data and laboratory expertise to facilitate the development of international standards and guidelines through the Joint FAO/WHO Food Standards Programme (i.e. Codex Alimentarius)
- Provision of expertise and training in laboratory quality assurance systems and analytical methodology to assist Member States in complying with standards for the implementation of regulatory programmes and to facilitate participation in international trade

Training

Training forms a major component of the activities of the Agency's Laboratories, with one wing being exclusively dedicated to this purpose. It houses a modern auditorium for up to 100 people, a large laboratory for practical exercises, an electronics training laboratory, an internet facility, and seminar and study rooms for fellows and trainees. These facilities, together with an excellent library and the modern laboratories, greenhouses, insect rearing facilities, etc. associated with the individual Units, are used for Interregional and Group Training Courses and for the training of fellows under FAO and IAEA Technical Cooperation Projects. During the past 5 years, almost 500 trainees from 84 Member States were trained for more than 65 man-years at the FAO/IAEA Agriculture & Biotechnology Laboratory.

Through its many activities in R&D, training and services, the FAO/IAEA Agriculture & Biotechnology Laboratory contributes to the sustainable transfer of appropriate adapted nuclear and related technologies that enable Member States to effectively address issues relating to sustainable agriculture.

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Soil and Water Management and Crop Nutrition

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SUSTAINABLE AGRICULTURE depends on maintaining an appropriate balance between the use and conservation of soil nutrients and water resources for crop and livestock production systems and environmental protection. The Soil and Water Management and Crop Nutrition (SWMCN) Subprogramme assists Member States in the use of nuclear techniques to develop improved and integrated soil-nutrient-water management practices for sustainable intensification of agricultural production systems as well as conservation of natural resources.

Soil and Water – the basic resources in agriculture for food security

- Approximately 75-80% of worldwide fresh water use is consumed by irrigated agriculture. This level of consumption is not sustainable because of the increasing competition for water from other sectors and the variation in rainfall patterns and global warming as a result of climate changes.
- Water use efficiency is intricately linked to nutrient utilization efficiency by crops. Thus an integrated approach to water-soil-nutrient management is vital to sustainable agriculture
- Poor agricultural management practices or intensification of agriculture without due regard to the sustainability of natural resources can lead to land degradation. Land degradation including soil erosion affects around 70% of the world's rangeland, 40% of rainfed agricultural land and 30% of irrigated land.

Nuclear and isotopic techniques in soil-nutrient-plant-water management

Nuclear techniques, which include stable and radioactive isotopes and radiation sources (neutron and gamma density probes), are used to:

- Measure rates of uptake, storage and cycling of water and nutrients in soil-plant and soil-plant-animal systems
- Quantify soil erosion/sedimentation rates as influenced by land management practices
- Investigate changes in soil productivity and quantify soil organic matter turnover as influenced by farming systems and practices
- Trace water movement and agricultural pollutant pathways and to quantify off-site losses of nutrients and water
- Assist in the selection of crop genotypes with superior resource use efficiency and tolerance to abiotic stress
- Quantify biological nitrogen fixation (BNF) of legumes in cropping systems.

Integrated soil fertility management

Isotopes such as nitrogen-15 (^{15}N), phosphorus-32 (^{32}P) and carbon-13 (^{13}C) are used as tracers to identify the most efficient management practices of locally available nutrient inputs (e.g.,fertilizers, organic nutrient sources, biological nitrogen fixation and phosphate rocks), tailored to specific cropping systems and environmental conditions for optimum crop production. Results from these activities include:

- A publication on "Guidelines on Nitrogen Management in Agricultural Systems".
- A joint FAO/IAEA bulletin (FAO Fertilizer and Plant Nutrition Bulletin No. 13) on "Use of phosphate rocks for sustainable agriculture".
- An IAEA-TECDOC publication on "Nutrient and water management practices for increasing production in rainfed arid/semiarid areas".

Arresting land degradation

Nuclear techniques have been employed to investigate management practices that mitigate land degradation (e.g. soil erosion, soil acidification and soil salinization) and enhance soil productivity. Outputs from these activities include:

- Incorporation of P-efficient crop species into cropping systems and amelioration of soil acidity and P infertility with lime and reactive phosphate rocks enhanced productivity of tropical acid soils
- ^{32}P isotopic techniques were successfully used to identify crop genotypes that are efficient in scavenging tightly-held soil phosphorus and to assess the agronomic effectiveness of indigenous phosphate rock sources
- Biological N_2 fixation (BNF) capacity, as determined by ^{15}N, of grain legumes (cowpea, common bean and soybean) commonly grown in the acid savannah soils of West Africa could be improved through rhizobial strain selection and plant genetic improvement
- ^{13}C was successfully used to estimate residence times of soil C derived from native vegetation and cultivated crops.
- The publication of a "Handbook for the Assessment of Soil Erosion and Sedimentation Using Environmental Radionuclides"
- Soil erosion rates, as measured by fallout radionuclide (^{137}Cs and ^{7}Be) techniques, ranged from 0.4 to 120 $t.ha^{-1}y^{-1}$, depending on factors such as rainfall intensity, soil characteristics, site topography, vegetation cover and land management practices.
- Soil conservation technologies such as no-till, grass strips and terracing in Morocco, Romania and Vietnam reduced soil losses by 55-89% as measured by fallout radionuclide techniques.

Non-tillage with vegetation cover

- Changes in land uses substantially reduced soil losses by 79% in Chile (with a change from crop land to grassland) and 81% in China (with a change from over-harvesting of timber to the restoration of the damaged watershed).

To date, some 40 Member States now have the capacity to use fallout-radionuclide techniques to estimate the beneficial effects of conservation measures on soil erosion/ sedimentation.

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Crop varieties with high tolerance to harsh environments and with superior resource use efficiency

One way of enhancing food security is to identify crop varieties that adapt to specific environments. The SWMCN subprogramme collaborates with the Plant Breeding and Genetics Subprogramme in identifying plants that are tolerant to abiotic stress (drought and salinity). The SWMCN Subprogramme is also concerned with the issues of low inherent soil nutrient status, in particular severe nitrogen (N) and phosphorus (P) deficiencies, which are the most common nutritional stresses for agricultural production in many regions of the developing world. Some specific activities include:

- Developing and validating screening protocols for plant traits that enhance N and P acquisition and utilization in major food cereal and legume crops grown in low fertility soils
- Facilitating the selection of drought-tolerant wheat and salinity-tolerant rice using ^{13}C discrimination techniques
- Facilitating the selection of crops for efficient phosphorus utilization by using ^{32}P isotopic techniques.

^{13}C is being used to identify wheat with high water use efficiency (WUE): Less discrimination against ^{13}C (less difference between ^{13}C and ^{12}C), the higher the WUE.

Conventional tillage with limited cover

Water Management in Agriculture

Improving water use efficiency in agriculture will require an increase in crop-water productivity through the use of novel irrigation technologies and an improvement in water management practices and soil moisture conservation measures at both farm and catchment levels. The measurement of natural variations in the abundance of 18O, 2H, 13C and 15N can be used for tracking and quantifying water and nutrient fluxes through and beyond the plant rooting zone. An accurate measurement of soil moisture content using nuclear (soil moisture neutron probe) and non-nuclear methods is essential for establishing the optimal soil-water balance for irrigation scheduling under different irrigation systems and soil management practices. Results from these activities include:

- Publication of "A manual on the use of soil moisture neutron and gamma density probes in agriculture"
- Publication of: "Practical guideline to field assessment of soil water content" (In press)
- Improving yield and revenue by 25-50% while reducing water use by the same extent in Chile, Jordan, Syria and Uzbekistan
- Publication of a book on "Crop Yield Response to Deficit Irrigation" and a joint FAO-IAEA publication (FAO Water Reports Series 22) on "Deficit Irrigation Practices".

Sustainable use and management of land and water: A must in sustainable agriculture

Nuclear and isotopic techniques play an important role in developing efficient water and soil nutrient management strategies for improving crop production, conserving natural resources and enhancing environmental protection.

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Plant Breeding and Genetics

Joint FAO/IAEA Programme
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AGRICULTURAL CROPS grown today have all undergone some form of improvement. This has been undertaken in many cases by selecting the best plants in the progeny of two or more different parents to combine their desirable characters. Mutation techniques and, more recently, biotechnologies became available to plant breeders to generate new variations that are crucial for developing novel crop varieties. The aim of crop improvement is to develop varieties which are higher in yield, more cost-effective and are able to grow under different, even adverse, conditions, or to provide a product that is more attractive to the consumer, i.e. with enriched (micro)nutrients. The Plant Breeding and Genetics Subprogramme of the Joint FAO/IAEA Programme assists Member States in the application of mutation techniques and supportive biotechnologies for the improvement of major food crops in marginal and stress prone areas and of local and often neglected crop species.

Nuclear techniques in plant breeding and genetics

Plant mutation techniques are based on the induction of changes in the hereditary material, the DNA. Irradiation of plant material such as seeds, buds, and plantlets with gamma rays, X-rays or neutrons, can result in changes in DNA sequence, rearrangement of parts of chromosomes, and loss or duplication of an entire chromosome or chromosome parts. Any of these changes can affect the function of the plant.

Rice is a major food crop in many developing countries: Vietnamese Rice Variety: VND95-21

Induced mutations

The discovery of mutagenic X-rays has enabled geneticists, for the first time in human history, to artificially create genetic variability. For more than fifty years, chemically and physically induced mutations have become an important and unique source of plant genetic variation. Their impact is measured in millions of hectares covered with mutant varieties and in billions of dollars of additional income. These mutations are also playing significant roles in various fields of biological research, such as the mutational analysis of plant traits, the discovery and deciphering of various genes and gene function and, of particular importance to plant breeders, the generation of novel alleles of agronomically important genes. Examples of important gene alleles that have been artificially induced and are today widely embodied in modern crop varieties include:

- Semi-dwarf gene 1 *(sd1)* in rice. The wide use of semi-dwarf rice and wheat varieties, carrying the *sd1* and *Rht1* allele, respectively, was the key contributor to the Green Revolution in the past century. The *sd1* gene in modern rice varieties in Japan, the USA and other countries was artificially induced by gamma rays, so that most of the semi-dwarf rice varieties now grown in countries such as the USA, Australia and Egypt are the derivatives of the semi-dwarf mutant variety "Calrose 76" and those in Japan of "Reimei".

- Mildew powder disease resistance in barley. Mildew powder disease is a worldwide, devastating disease in barley. The wide resistance spectrum of the highly resistant gene allele, ml-o, first induced by X-rays in the variety "Diamant", has become the most widely used resistant gene allele against this disease in Europe and in large regions of the world today, playing a key role in world barley production.

Developing new varieties

Mutation techniques have become safe and undisputed breeding tools in the development of new plant varieties, leading to the generation of novel alleles that had not previously been isolated in particular varieties (e.g. high stearic acid content in sunflower); the further improvement in a few characteristics of already well performing varieties; and the facilitation and/or supplementation of other breeding technologies, such as the irradiation of pollen for parthenogenesis in doubled haploid production.

Almost all agronomically important characters can be improved using mutation techniques. The most frequently reported mutations in new mutant varieties are:

- Earliness
- Better yield potential and yield related traits
- Disease resistance
- Quality parameters
- Salinity tolerance

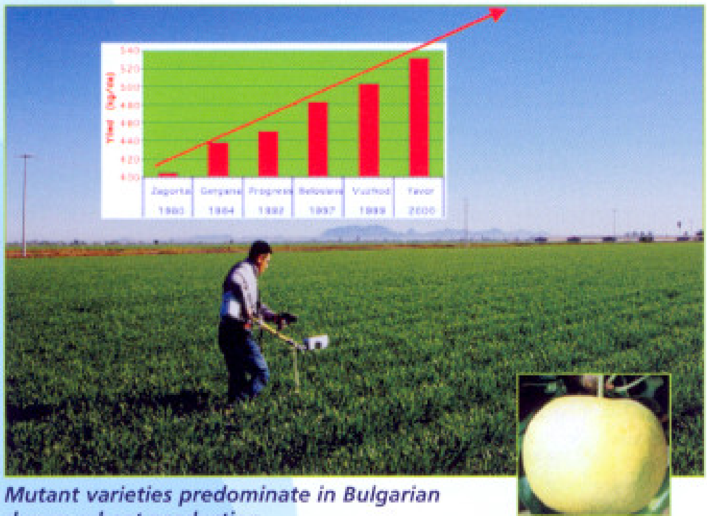
Examples of improved varieties

VND95-21, one of the many successful rice mutant cultivars, is a leading, high quality rice variety grown in the Mekong Delta area, where most of the export quality rice is produced in Vietnam.

Yangmai 158, a mutant wheat variety widely grown in the Yangtze region in China since the early 1990s, with a cumulative area of more than 10 million ha.

Progress is a mutant durum wheat variety that, together with other mutant varieties, has steadily pushed yield potential to new heights in Bulgaria.

Gold Nijisseiki was developed from mutants induced by chronic gamma-ray irradiation and released in Japan, where its resistance gene has protected pear production from the devastating black spot disease and has generated economic returns of tens of millions of dollars in additional income per year.



Mutant varieties predominate in Bulgarian durum wheat production

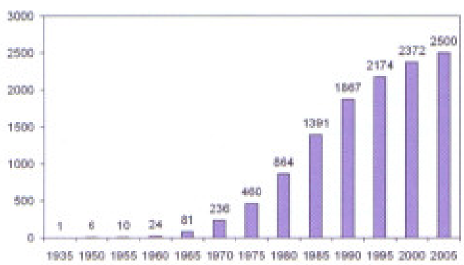
Mutant varieties keep yield increasing steadily in Bulgarian durum production.

Mutation breeding of durum wheat in Bulgaria started in the 1980's, resulting in 5 popular varieties. A new variety becomes predominant in 8-10 years after release.

Gold Nijissei

Mutant varieties database

Data of mutant varieties officially released have been collected and deposited in the FAO/IAEA mutant varieties database (MVD). This database contains information on mutagens used and characters improved of more than 2500 varieties. Each year the number of officially released varieties increases steadily, demonstrating the continuing popularity of this technology.



Officially released mutant varieties, showing the accumulated total during 70 years of mutation breeding

Related biotechnologies

Biotechnologies can be synergistically used with mutation techniques to enhance efficiency and effectiveness in the development of novel, improved varieties. Most often, biotechnologies are used to facilitate *in vitro* mutagenesis and selection, to accelerate the process of mutation fixation and to facilitate selection at the DNA level.

In vitro techniques

In vitro culture techniques, which permit growth of millions of cells in the laboratory and allow the production of large populations of plants, can be used to speed up the plant breeding process. In vitro cultures are good materials for mutation induction and subsequent selection, e.g. the development of breeding lines tolerant to salinity. This technique is particularly important, if not mandatory, for the improvement of vegetatively propagated crops, such as banana, plantain, potato, cassava, and sweet potato.

Doubled haploid techniques

The Doubled Haploid technique is an *in vitro* technique that can be used to obtain stable and homozygous mutants following mutation induction, and to produce new promising lines in just 3 to 4 generations.

Molecular marker techniques

The use of DNA markers is becoming a successful adjunct to plant breeding. Their usefulness is evolving for characterizing genetic diversity in crops and wild relatives, and for more rapid introduction of traits and induced mutations into cultivated germplasm through processes called marker assisted selection, marker assisted back-crossing and marker assisted pyramiding of gene alleles. Molecular markers are particularly useful when they are closely linked to agronomically interesting mutations, since they can then assist breeders to introgress these mutated genes into various breeding programs.

Molecular detection of mutated genes

Novel DNA technologies have recently become available for detecting mutations at the DNA level. The most prominent example is the development of a new technique known as Targeting Induced Local Lesions in Genomes, TILLING. By using the TILLING technology, geneticists are now able to detect every single nucleotide change of a gene of interest in a large population and plant breeders can detect recessive mutations in the still hetero/hemizygous mutant plant generation. Therefore, these new technologies are not only significantly increasing the effectiveness of mutation detection, but also the usefulness of mutation techniques for crop improvement.

Through the application of mutation techniques, farmers can be provided with new varieties with better adaptability and resistance to different environmental stresses. This contributes to the intensification of food production and the achievement of food security.

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Animal Production and Health

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

LIVESTOCK ARE VITAL to sustainable agriculture in most developing countries and much of the economic growth potential of these countries depends on the successful implementation of good agricultural practices. Industrialization and urbanization increase the demand for livestock products by consumers and have led many developing countries to increase their imports of animal products and intensify their livestock production. Intensive production may impose a cost on animal health and the environment. Proper management of animal nutrition, reproduction, and health is the key to maximizing the benefits and minimizing the costs of livestock production systems. Nuclear and related technologies are useful tools in research and development, which provide the basis for formulating appropriate management strategies for improving livestock productivity. The Animal Production and Health Subprogramme assists Member States in the development and use of these technologies through strategic and applied research, technology transfer and training.

The objective of the Animal Production and Health Subprogramme is to enhance food security in Member States by supporting sustainable intensification of animal production.

Nuclear techniques to improve productivity

Isotopes of carbon, chromium, nitrogen, phosphorus and sulphur can be used as markers to monitor the behaviour of nutrients in the digestive system and the body of animals. This information provides the basis for developing cost effective feeding strategies for improved animal nutrition and productivity. Using isotopes it is possible to understand:

- how feed materials are digested
- how micro-organisms in the rumen digest forages
- how different nutrients are utilized
- how nutrients are used for growth, reproduction and lactation
- what nutrients are deficient or unbalanced

The measurement of reproductive and other hormones by radioimmunoassay (RIA) gives a better understanding of the reproductive physiology of livestock. For example, the amount of progesterone in blood or milk is used to determine:

- onset of puberty
- resumption of ovarian functions after parturition
- ovarian dysfunction
- oestrus detection efficiency
- non-pregnancy

Isotopes and other materials can be incorporated into nucleic acids and used as markers to detect specific DNA or RNA sequences. This information is valuable for:

- selecting animals with favourable genes
- certifying an animal's identity or parentage
- determining the evolutionary history of a breed
- measuring gene expression
- detecting pathogens
- inactivating pathogens (gamma-irradiation)

Animal Nutrition

The main constraint to livestock production in developing countries is the general scarcity and fluctuation of the quality and quantity of the feed supply during the year. Grain crops are primarily grown for human consumption and feed concentrates such as soybean, cottonseed and groundnut meals are in short supply. These problems are compounded by the loss of arable land due to urbanization, industrialization and soil degradation.

A key objective is to enhance the efficiency of utilization of locally available feed resources such as tree and shrub leaves, agroindustrial by-products and new plants adapted to harsh conditions and poor soils. This is achieved by developing better methods for determining the nutritional value of these feedstuffs and using them in 'simple-to-use' feeding strategies. Such work is being undertaken in many countries through FAO/IAEA coordinated research projects and technical cooperation projects. Promising plants/by-products are being incorporated into new feeding strategies, e.g. urea molasses blocks, and their effects on ruminal microbial communities and the amount of nutrients and wastes produced by ruminal fermentation are being measured.

Many small-holder farmers in rural areas depend on animals for their livelihood.

Reproduction and Breeding

Efficient reproduction and breeding form the foundation for sustainable improvement of animal productivity and are critical factors influencing the economic stability of livestock farmers. Key activities support the adoption of an integrated approach to improving reproduction and breeding, using a wide variety of methods and technologies. Many of the activities relate to the adoption and subsequent management of artificial insemination programmes. Included are interventions to monitor reproductive cycles and improve female fertility, education to increase the skill of inseminators, and consultation on the development of breeding and selection programmes. To promote the utilization of indigenous resources, several projects involve the characterization of livestock using both phenotypic and molecular approaches.

Animal Health

Livestock diseases remain a key problem to the economic growth of most developing countries, and their control and ultimate eradication is vital. The main thrust in the Animal Production & Health Subprogramme is to help countries develop disease control strategies in a sustainable way through the transfer and support of appropriate nuclear and related technologies.

There are many diseases requiring attention, but those which require most urgent attention are:

Diseases

- **Rinderpest**
- **Foot-and mouth disease**
- **Brucellosis**
- **Trypanosomosis**
- **Tick-borne disease**
- **Contagious bovinepleuropneumonia**
- **Newcastle disease**
- **Avian Influenza**

For all these diseases there is a substantial research background in developed countries. This research capacity has been harnessed by the Joint FAO/IAEA Programme to promote the use of defined reagents and methods for disease diagnosis and monitoring of control programmes. Specific guidelines, standard operating procedures, reagents and kits have been developed for these purposes and transferred to be used by Member States. The major technologies utilized are serologically and molecularly based (e.g. Enzyme Linked Immunosorbent Assay and Polymerase Chain Reaction).

ELISA

This technology is the most commonly used diagnostic system in veterinary and medical sciences. Enzyme Linked Immunosorbent Assay (ELISA) has been exploited to diagnose a wide variety of diseases by identifying the agent itself and/or the antibodies produced against the agent. A colour reaction is read at the end of the assay. The assay can be used to test thousands of samples quickly, so it is highly suitable for processing large numbers of samples. The results are quantifiable and can be analyzed statistically, which means that they can be compared and standardized across laboratories.

PCR

Molecular biology has been revolutionized by amplification technologies of which the Polymerase Chain Reaction (PCR) is the most prominent and widely used. PCR enables the amplification of a single molecule of target nucleic acid into millions of exact copies that can be visualized by using radioactive or fluorometric markers. The amplification step makes this technology extremely powerful because it enables the presence of small amounts of pathogens (virus, bacteria or protozoa) to be detected in sick animals. In addition, by characterizing the genome of a particular animal or plant, more resistant species can be selected in specific problematic areas and improved reproduction and nutrition strategies can be implemented.

Due to the success of the global rinderpest eradication programme, Africa is today free from the rinderpest threat. This represents an annual economic benefit of at least $1 billion to the region.

Nuclear and related techniques make an important contribution to efforts to improve livestock productivity and food security through better management of feed resources, reproduction and control of diseases.

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Insect Pest Control

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INSECT PESTS have devastating effects on crop production and trade and transmit diseases that affect crops, livestock and humans. Conservative estimates indicate that pests deplete world food production by 25% to 35%, in spite of continued growth in insecticide applications. As a result of this often-heavy reliance on insecticides, concerns about the environment and pest resistance have grown considerably. The overall objectives of the Insect Pest Control Subprogramme of the Joint FAO/IAEA Programme is to reduce losses in agricultural commodities, to limit insecticide use and its negative impact on the environment and to facilitate trade through the development and implementation of environmentally friendly nuclear techniques for **integrated area-wide management** of key insect pests.

Insects in perspective

Over a million insect species exist, most of which are harmless or even beneficial to mankind:

- Pollinators – bees and other insects
- Predatory and parasitic insects, ladybirds and wasps
- Food-chain – prey for birds and other animals
- Honey and wax-bees
- Silk producers – silkworm and other silk moths

Of all the insect species:

- About 100 insect pests account for 90% of all losses and these key pests are the target of most insecticides used worldwide

The challenge of pest management

Modern human societies do not tolerate natural levels of insect damage, and it is unavoidable that insect pests have to be suppressed. The present over-reliance on chemical pesticides to control insect pests cannot be sustained in the future. This is because they can result in:

- Increasing pesticide resistance in target species
- Presence of residues in food that may affect human health and restricts commercialization
- Widespread environmental pollution
- Contamination of groundwater
- Emergence of secondary pests as a result of the elimination of natural enemies

It is therefore essential that pest control measures are not only effective, but also ensure that biological diversity and the environment are preserved.

Genetic control methods

Radiation is highly effective in sterilizing insects, and this property is the basis of genetic or autocidal methods for controlling agriculturally important pests. The best-known method of genetic pest control is the Sterile Insect Technique (SIT).

Sterile Insect Technique (SIT)

The Sterile Insect Technique is an environment-friendly method of pest control that has proved highly effective against several key insect pests. These include:

- Fruit flies – several species
- Screwworm flies – both the New and Old World screwworms
- Tsetse flies– several species
- Lepidoptera – several caterpillar/moth pests

Pest insects are maintained in fly factories for large-scale production of offspring that are exposed to a precise dose of gamma radiation. The radiation is sufficient to induce sterility but does not affect the ability of the treated males to fly, compete with wild insects, mate and transfer sperm. The treated insects are normally released by air on a systematic and sustained basis into target areas, and by substantially reducing fertile matings they suppress the pest populations, and in special situations may even lead to eradication. Other management techniques complement the SIT to reduce the native populations so that fewer sterile insects are required. In this way, the SIT integrates well with other insect management techniques to achieve a more environment-friendly control.

Fruit flies

The Mediterranean Fruit Fly *(Ceratitis capitata)* attacks over 250 species of fruit and vegetables. Females puncture fruit when they lay eggs and hatched larvae destroy the fruit. Their economic consequences are so great that countries free of Mediterranean fruit fly (Chile, Japan, New Zealand and USA) prohibit the import of fresh produce from countries where the pest is endemic. With advice and assistance from the Joint Programme, the SIT has been used successfully to sustainably suppress (Argentina, Israel, Spain, South Africa, Mexico, Thailand, Tunisia), contain (Australia, Guatemala, Peru), or even eradicate (Argentina, California, Chile, Florida, Mexico) this pest from entire regions or countries, opening new export markets and bringing about substantial economic and environmental benefits.

Fruit market in Guatemala

Anastrepha **fruit fies** are the main fruit fly pests throughout the Western Hemisphere. The SIT has been applied to exclude the Mexican fruit fly *(A. ludens)* from California and Texas, to suppress the Caribbean fruit fly *A. suspensa* in Florida, and to eradicate *A. ludens* and the West Indian fruit fly *A. obliqua* from northwestern Mexico. The SIT is also being developed for use against *A. fraterculus* in South America.

Bactrocera **fruit flies** are the main fruit fly pests throughout the Asia-Pacific region. The melon fruit fly *(Bactrocera cucurbitae)* is a major pest of cucurbit crops. Integrating the SIT on an area-wide basis with suppression measures, this pest was eradicated from all islands of the Okinawa archipelago in Japan. In Thailand the oriental fruit fly *B. dorsalis* and the guava fruit fly B. correcta, and in the Philippines *B. philippinensis* are being suppressed to reduce losses in mango.

Already a considerable number of fruit fly mass-rearing factories are in operation in the world. The incorporation of genetic sexing strains for male-only releases is further enhancing the economic and technical advantages of the SIT, promoting the routine and sustainable use of sterile males and thus commercialisation of the SIT.

Moth pests

Caterpillars are major pests in forests, stored grains, and fibre and food crops. Pest resistance to insecticides is an increasing problem and moths are among the most feared invasive species. The SIT is increasingly being developed for the integrated management of a number of moth pests. It is being applied to suppress the codling moth *(Cydia pomonella)* in apples and pears in Canada and the false codling moth (*Cryptophlebia leucotreta)* in citrus in South Africa, to contain the pink bollworm *(Pectinophora gossypiella)* in cotton in California, and to eradicate the invasive painted apple moths (*T. anartoides)* in New Zealand. It is also being developed to contain the invasive cactus moth *(Cactoblastis cactorum)*, the carob moth *(Ectomyelois ceratonia)* in dates, and the diamondback moth *(Plutella xylostella)* in crucifer vegetables.

Screwworms

The New World Screwworm *(Cochliomyia hominivorax)* is an destructive and often fatal pest of all warm-blooded animals, including humans. It lays eggs into animal wounds and on soft tissues such as the nose, navel and anus. The larvae burrow through the flesh creating bacterial infections that attract more egg-laying females.

This pest was once endemic throughout the Western Hemisphere, but has been eradicated from the USA, Mexico and Central America using the SIT. Campaigns to eliminate the pest from the Caribbean continue. In 1988 the pest was found in Libya and an urgent national and international effort was mounted integrating the SIT to prevent its spread to livestock and wildlife in the rest of Africa and the Mediterranean Basin. The campaign was successful in achieving eradication, preventing the enormous losses, which would have occurred if the infestation had spread and become permanently established.

Tsetse

Tsetse flies and the disease trypanosomosis it transmits, are responsible for the separation of livestock keeping and crop production in Sub-Sahara Africa. As a result, productive mixed crop-livestock farming as shown above is still a rare exception in African agricultural practices. Inset: sterile male tsetse fly mating with a virgin female.

Tsetse Flies *(Glossina spp.)* are a scourge of Africa. There are several economically important species, all of which feed on blood and transmit the *Trypanosoma* parasites, which are responsible for sleeping sickness and animal trypanosomosis or 'Nagana' in cattle. The continuing presence and advancement of tsetse into new agricultural systems prevents sustainable and profitable livestock systems in almost two-thirds of sub-Saharan Africa. Since agriculture cannot function effectively without the benefits of livestock – traction power for transport and ploughing, manure for fertilizer and fuel, and nutritious food products including meat and milk – tsetse is at the very root of poverty.

SIT for Tsetse: Over several decades, the Joint Programme has developed the SIT against the most important tsetse species. It is effectively used where natural populations have been reduced by traps, insecticide impregnated targets, or the aerial application of the sequential aerosol technique. The area-wide release of sterile males, sustained over a few fly generations, can ultimately eradicate a tsetse population. A project with the Tanzanian Government, using sterile males from the tsetse production facility in Tanga on mainland Tanzania, eradicated the only tsetse species, *G. austeni*, from the Unguja island, Zanzibar. The feasibility of applying this integrated area-wide approach over larger areas on the African mainland is currently being investigated in Ethiopia and at various other sites near the northern and southern edge of the tsetse belt.

Refining SIT procedures and techniques

Researchers at the Entomology Unit of the FAO/IAEA Agriculture & Biotechnology Laboratory, in collaboration with FAO/IAEA coordinated research networks involving researchers in many countries, continue to develop the SIT against other species and to further refine methods to improve its efficiency and reduce its cost. Important breakthroughs include:

- **Mediterranean fruit fly** Genetic sexing strains, involving temperature sensitivity in which only female eggs are killed when eggs are immersed in water at a critical temperature, permit the release of males only. This increases the effectiveness of the SIT and reduces the cost of rearing flies, and has been transferred to most Mediterranean fruit fly mass rearing facilities in the world, reaching a total production of close to 4 billion sterile males per week.
- **Tsetse** Membrane feeding, pupal sex separation and semi-automated rearing considerably increase production capacity, standardize quality sensitive rearing processes, decrease production costs and eliminate animal rights issues.

Nuclear techniques make an important contribution to biological control of insect pests. The Insect Pest Control Subprogramme of the Joint FAO/IAEA Programme continues to develop and refine modern technologies and contribute to the preparation of international plant and animal health standards in support of sustainable and improved agricultural production and trade.

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Food and Environmental Protection

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

MANKIND'S ENDEAVOUR to ensure an adequate supply of safe and wholesome food continues today as it has throughout the centuries. Despite these endeavours, millions of people regularly lack sufficient food to ensure good health while others suffer ill effects from lack of food or from food contaminated by microorganisms. Careless use of chemicals is a further risk, not only to consumers and to the environment but also to a country's international trade opportunities. The Food and Environmental Protection Subprogramme of the Joint FAO/IAEA Programme develops and transfers nuclear and related technologies and skills in the application of international standards that ensure food quality and safety throughout the food production chain, including in the safe and efficient use of agricultural production inputs, and having in place emergency procedures to minimize the risk of pollution or contamination from nuclear accidents or radiological events.

Irradiation

Post harvest food losses due to damage by insects, rodents, bacteria and mould, or from sprouting or over-ripening of produce, are estimated to be between 25% and 40% in many developing countries. The benefits for food security would be considerable if these losses were reduced. Irradiation is an effective and safe method for preserving food by subjecting it, under controlled conditions, to ionizing energy, and is today a widely used technology for the preservation of spices and other commodities. Irradiation:

- Reduces spoilage
- Improves food hygene
- Extends shelf life

Irradiation and the Consumer

When given a choice and proper information, consumers have not only become more willing to purchase irradiated foods but have often bought these foods in preference to foods treated by other processes.

Public health authorities are concerned about the increasing incidence of foodborne disease caused by pathogens such as Salmonella and new and more virulent bacteria such as E.coli 0157.H7. Furthermore, modern large scale production and processing of food means that large numbers of consumers over a wide geographical area can be put at risk from a single batch of contaminated food. Irradiation, similar to thermal pasteurization of liquid food, e.g. milk, can ensure the hygienic quality of solid foods, e.g. poultry and red meat, seafood, or spices, without significantly changing their quality. It is ideally suited for foods of animal origin, especially those to be consumed raw or minimally processed.

A safe alternative to chemical fumigants

Some of the chemical fumigants used to treat agricultural products after harvest are being phased out. Ethylene and propylene oxides (which are used to treat spices), and methyl bromide, (which is used to treat agricultural crops) leave potentially harmful residues on treated products. They also affect air quality and therefore human health. Ethylene oxide is now classified as a carcinogen and methyl bromide is one of the most potent ozone layer depleting agents known.

Irradiation is a safe alternative; it is safe for those working with the application process, for consumers, for the general public, and for the environment.

Irradiation and Food Security

Irradiated foods last longer and can be more accessible to a greater number of people at lower cost. This can also have a significant effect on rural incomes because producers are able to sell a higher proportion of their production. The ability to store produce without risk of spoilage evens out fluctuations in food availability and price and so improves food security, especially for those on low incomes.

International Standards and Trade

Food Irradiation: The Codex General Standard for Irradiated Foods, which is accepted by national authorities in many countries, is based on work by joint FAO/IAEA/WHO Expert Committees. The endorsement of the safety and effectiveness of food irradiation by the Codex Alimentarius Commission provides important incentives to governments and industry for the increasing use of irradiation for sanitary purposes.

Quarantine: The US Department of Agriculture's Animal Plant Health Inspection Service has recently issued a new policy which allows irradiation as a quarantine treatment of fresh fruits against fruit fly infestation. Fruits which have been irradiated for this purpose have already entered commercial channels in the USA.

Food and Pesticides: Codex sets standards for maximum permissible levels for contaminants, such as mycotoxins, and residues, such as pesticides and veterinary drugs, in international trade; they are often also used in national legislation. Similarly, FAO specifications for the composition and quality of pesticide products are used both internationally and nationally. Monitoring food contaminants and pesticide products requires analytical facilities and trained personnel. The Food and Environmental Protection Subprogramme helps Member States to develop such laboratories to support national laws and international agreements, including the WTO Agreement on the Application of Sanitary and Phytosanitary Measures. The implementation of controls on food and pesticides protects consumers and helps exporters to ensure that their products meet the requirements of importing countries.

The transfer of practical field skills related to pesticide management

Training and Reference Centre for Food and Pesticide Control

This centre is at the heart of the efforts to support laboratories engaged in food and pesticide control. Based at the IAEA's Seibersdorf Laboratories, the Centre provides a comprehensive and harmonized response to requests from Member States for training, expert advice and other services needed to bring standards in developing countries to internationally accepted levels so that their results are accepted in all countries.

Fellowship training on pesticide control in the Seibersdorf analytical laboratories

Nuclear and Radiological Emergencies

Accidents such as Chernobyl, which result in radionuclide fallout, have far reaching effects, not only on human health and the environment but in particular on agriculture. The Food and Environmental Protection Subprogramme of the Joint FAO/IAEA Programme gives advice on contamination as it relates to agriculture.

Monitoring techniques developed by the Joint FAO/IAEA Programme have established that it is safe to grow oilseed rape for the production of biodiesel oil and grease since any radioactive contamination taken up by the plant is not extracted with the oil and remains in the plant residues that are discarded. This has meant that previously useless land is now productive and countries have a source of indigenous fuel for which it would otherwise have to depend entirely on imports.

The availability of safe and wholesome food requires that crops and animals are protected against pests and diseases using methods that do not cause unacceptable risks to humans and the environment. In addition, free international trade in agricultural commodities is essential. Food irradiation and analytical methodology for detecting contaminants are important for supporting national and international efforts to meet these aspirations.

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