Tropical Agricultural Research and Extension

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Special Issue
on

Nuclear Techniques for Better Agricultural Productivity

Published by the Faculty of Agriculture, University of Ruhuna and the Atomic Energy Authority of Sri Lanka.

FOREWARD

Unlike many other technologies developed in the west, developing countries have been able to reap the benefits of nuclear technology, particularly in agriculture and food industry through the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture established in 1964 in Vienna. In a world where one billion people are going to bed hungry each day and millions dying of hunger, malnutrition, and related causes, nuclear science techniques will play an important role in food production. These techniques find application throughout the value chain of agriculture from development of new improved crop varieties to food preservation and safety. Other major areas where nuclear techniques are playing an effective role in agriculture include improving soil and water management, efficiency of fertilizer usage, understanding the origins and causes of soil salinity and erosion, understanding plant and animal metabolic pathways, biogeochemical cycles, diagnosing animal diseases and controlling insect pests.

Plant mutation breeding started with seed irradiation experiments in the 1940's and has been extended to vegetatively propagated crops including *in vitro* systems resulting in the release of more than 1800 new crop varieties worldwide. The major advantages of these techniques over conventional plant breeding methods include quicker development of new crop varieties, targeted genetic manipulation for plant improvement including applications to species that do not produce seeds preventing conventional hybridization. Double haploid technique and DNA fingerprinting procedures are now used in conjunction with mutation techniques to enhance the mutant development process. Radioisotopes are also used in genetic engineering, an alternative to conventional plant and animal breeding. Radiolabeling is an important tool in modern gene technology, for example in the detection of RNA quantities of less than a picogram (one trillionth of a gram) in a transcription reaction.

Fertilizers are an important but expensive input in modern agriculture. In plant nutrition studies, isotopically-labeled fertilizers are used to estimate fertilizer recovery by crops, residual amounts in soil and losses by either mass balance or direct measurement allowing optimization of fertilizer application. Both stable (^{15}N) and radioactive (^{32}P, ^{33}P) isotopes have been used for many decades but the cycling of carbon and sulphur in the soil-plant-animal-atmosphere system, using stable isotopes (^{13}C, ^{34}S) is relatively new compared to radioactively labeled materials (^{14}C, ^{35}S). The use of stable isotopes in plant nutrition, soil fertility, and ecological and environmental studies has increased considerably over the past decade. Stable isotopes occur naturally and by monitoring changes in their distribution and natural abundance in soils and plants we can obtain important information on the functioning of ecosystems, organic matter dynamics and water use by plants. Isotope methods have made valuable contributions to our knowledge of nitrogen fixation, photosynthesis, biochemical pathways, fertilizer efficiency, uptake of nutrients and their physiological function in plants. Until recently, estimating a plant's root biomass and nutrient content, where roots are dug up, separated from the soil with a sieve, washed and weighed has been a tedious task. Foliar labeling technique has made this task much easier, giving more accurate and reliable results. This technique has demonstrated that conventional methods have underestimated belowground plant-derived nitrogen by as much as 50%. Soil nutrient dynamics, including loss by leaching can also be studied using isotopes. In addition to mass spectrometry and emission spectrometry, techniques such as nuclear magnetic resonance, gas chromatography-mass spectrometry and automated nitrogen and carbon analysis-mass spectrometry are playing an increasingly important role in soil fertility and plant nutrition research. Another application that is finding wider use is $^{13}C/^{12}C$ discrimination in C_3 plants to identify genotypic differences in water use efficiency. Most of these methods give direct results with high accuracy and reliability.

Soil organic matter, which is critical in tropical agriculture, can be assessed using natural abundance techniques, in particular to estimate turnover rates of soil organic matter. Techniques to label plant material with either one or two isotopes permit the simultaneous estimation of the fate of several organically bound elements like carbon, nitrogen or sulphur during the decomposition of plant residues or manures. The use of the isotope dilution technique as an alternative to direct labeling of fertilizers or plant residues is also useful in such studies. It has been used widely for measuring biological nitrogen fixation (BNF) because it can discriminate between nitrogen fixed from the air and that assimilated from soil nitrogen sources. For example, this has led to the identification of legume genotypes with high BNF capacity, to which efficient *Rhizobium* bacteria strains can be matched for making biofertilizers. New techniques using fallout radionuclides to measure soil erosion involving ^{137}Cs have been reported in recent years. Caesium binds strongly to clays and it has a relatively long half-life, making it an ideal marker for following the movement of eroded soil particles.

Water resource management is another area where isotopic studies are providing important information. They can trace and measure the extent of underground water resources, artificial recharge of ground water system, silt movement in ports and lakes, flow measurements in rivers and seepage identification in dams, thereby assisting in the management of existing supplies of water and in the identification of renewable sources. Natural abundance stable isotope research is an emerging area with great potential. Isotope ratio mass spectrometry can provide clues to the origin, age, distribution and the interconnections between ground and surface water. The results permit informed recommendations for the planning and management of the sustainable use of water resources. Hydrology data generated by isotopic techniques can provide vital information for managing water resources more effectively.

Salinity is another major soil problem not only for agriculture but also for sustaining human settlements. Isotopic analysis of salts is a valuable tool, which enables the movement of saline water to be monitored. Neutron moisture probes are helpful in better managing irrigation (or even rain) water, thus avoiding excess water use, which can be a cause of salinity due to the water table rising. Selection and cultivation of salt-tolerant species in saline soils can be optimized using isotopes. An inter-regional project to reclaim salt-affected barren land using nuclear techniques is underway in eight countries. The results are likely to be applicable to other countries having similar problems.

Knowing the precise isotope ratios in plant and animal tissues allows us to know about the processes by which the material is formed. It is possible to understand if a plant's roots are tapping recent rain or underground water, the water-use efficiency of whole forests, the food an animal has eaten throughout its life and where it sits in the food chain. Historical materials can be analysed in the same manner, allowing us to compare modern and ancient environments. Throughout the world today, essential biogeochemical cycles are being altered to an unprecedented extent by human activity. Although not all the changes may be harmful, understanding the consequences of anthropogenic impact and which ecosystems are under threat is an urgent challenge for environmental biologists. Isotopic techniques will play an increasingly valuable part in such studies.

Crop losses caused by insects are highest in the tropics reaching 30% in the field. Chemical control with insecticides has been practiced for many years but they have not always been effective. Some insects have acquired resistance to these insecticides and many insecticides leave poisonous residues on the crops. In the Sterile Insect Technique (SIT) large batches of male insects are reared in the laboratory, sterilized using radiation before they hatch, and then released in the infested areas. When they mate with females, no offspring are produced. With repeated releases of sterilised males, the population of the insect pest can be drastically reduced. It is estimated that the control of Mediterranean fruit fly and screwworm in Mexico using SIT has yielded US$ 3 billion in benefits to the economy. The screwworm, which has been endemic throughout the Western Hemisphere, has now been eradicated from the USA, Mexico and Central America using SIT. Similarly, the control of tsetse fly in the Tanzanian island of Zanzibar in 1997 using this method has encouraged the Organization of African Unity to join forces with the IAEA in a continent-wide campaign against tsetse fly. This fly is responsible for the transmission of trypanosomiasis or sleeping sickness affecting half a million people in Africa with an 80% mortality rate. SIT affects only the reproduction of the target insect whereas insecticides can cause the death of pollinators and natural enemies of the pest, in addition to the pollution of the environment.

Post-harvest losses of food as a result of spoilage by microbes and pests are estimated at 25-30% worldwide. Losses are higher under hot and humid conditions of tropics. There is an increasing trend in the use of irradiation technology to preserve food throughout the world. Health authorities of many countries have approved irradiation of a variety of foods including spices, grains, fruits, vegetables, fish and meat. A worldwide standard adopted in 1983 by a joint committee of the WHO, FAO and IAEA allows free trade of irradiated foods. This has allowed developing countries to meet stringent standards of quality required by developed countries where their products are sold. Radiation is now widely used to sterilise both food and food packaging. There is considerable potential for wider application of this technology. Irradiation can significantly reduce the risk of pest and disease transfer between countries or regions. Today, there is a large volume of food products contaminated by soil in world trade, such as potato, cassava or sweet potato, which are often infested with insects, nematodes and fungi. Instead of fumigating with toxic and environmentally harmful chemicals, irradiation can effectively control these pests by rendering them sterile. Radiation technology also can effectively control food-borne diseases caused by pathogens such as *Salmonella* and *E.coli.* This technology is finding wider application in meat and seafood preservation, as the quality, taste or texture of the product is unchanged.

In animal production nuclear techniques have offered solutions to many problems. For example, these techniques have been helpful in determining the digestibility and utilization of feeds and deficiency or the imbalance in nutrients during the development process of feed supplements for ruminants. The multi-nutrient mixtures developed with the aid of radioactive and stable isotope tracer techniques have significantly increased milk production in dairy cattle and buffaloes in the tropics. Radioimmunoassay (RIA) is a nuclear technique used to measure the levels of reproductive hormones in farm animals. Blood or milk can be used to measure the level of progesterone using RIA. Through a better understanding of the reproductive physiology of different animals, monitoring of farm animals can be put on a scientific basis. Such information is useful, for example in calculating the onset of puberty, resumption of ovulation after parturition, time of oestrus, ovarian dysfunctions etc. It is also an important tool for determining feed supplements, grassland management, animal rearing practices, timing of artificial insemination and hormonal treatment. ELISA (enzyme linked immunosorbent assay) is another widely used diagnostic tool in veterinary and medical sciences. It was effectively used for eradicating rinderpest in Africa. The technique is very practical for developing countries as it comes as a field kit and can efficiently and economically process large numbers of samples to diagnose disease. ELISA kits are available for a wide variety of diseases as well. The successful approach of the Pan-African Rinderpest Campaign is now being used as a model for control of other diseases, such as Contagious Bovine Pleuropneumonia, foot-and-mouth disease, brucellosis and tick-borne diseases.

From the foregoing it is evident that nuclear technology has brought very significant benefits to agriculture. This has included a wide variety applications such as improving a deficient characteristic in an otherwise desirable crop variety, tracing the flow of water and nutrients in soil strata, tracking nutrients in plants or animal digestive systems, controlling entire pest populations without affecting other fauna, measuring minute levels of hormonal variation in livestock, accurately identifying animal disease in the field etc. Lack of understanding, and sometimes misunderstandings about nuclear technology can be a barrier to future progress. The dissemination of research findings is important for maximizing the benefits of this technology.

It has been a challenge to compile the results of application of nuclear techniques in agricultural research in Sri Lanka as most of the projects were funded by the IAEA and the institutes reported direct to the Agency. One way to compile a comprehensive document was therefore to hold a symposium and publish the proceedings. The Faculty of Agriculture, University of Ruhuna with the assistance of the Sri Lanka Atomic Energy Authority and the Sri Lanka Association for the Advancement of Science undertook this challenge and the result is this publication representing a selection of papers presented at the symposium. As evident from these proceedings, Sri Lanka like many other countries of the developing world has benefited by the research assistance of the IAEA all along the food value chain, from development of new crop varieties to preservation of the final product. It is hoped that this publication will serve as a basis for the formulating and launching of further research in the area of nuclear agriculture for the benefit of both farmers and consumers.

Professor Ranjith Pathirana
Editor-in-Chief

MESSAGE OF THE CHAIRMAN OF THE ATOMIC ENERGY AUTHORITY

It is with pleasure that I issue this message for the special issue of the Journal, "Tropical Agriculture Research and Extension", which contains the proceedings of the Seminar on Nuclear Techniques in Agriculture, conducted by the Atomic Energy Authority in collaboration with the Sri Lanka Association for Advancement of Science (SLAAS). The publications in this issue are based on the research projects implemented with the Technical Assistance of the International Atomic Energy Agency.

The Atomic Energy Authority (AEA) as the national focal point of the International Atomic Energy Agency (IAEA) in Sri Lanka has the responsibility of managing the Technical Cooperation Programme of the IAEA. This includes selection of the projects to be implemented based on established criteria, coordination of the implementation of the projects, monitoring their progress, and providing support scientific services needed for their implementation. It is the policy of the AEA to ensure the country benefits from the projects implemented under this programme, through contributing to improving the agricultural productivity.

Similar to many other Member States of the IAEA, nuclear techniques have been and are being used in Sri Lanka, for developing improved crop varieties by radiation induced mutation breeding, optimizing fertilizer usage through studies conducted using radioisotope labeled fertilizers, optimizing irrigation by the use of neutron moisture probes, making use of atmospheric nitrogen fixation to reduce the use of nitrogen based fertilizers through studies using stable isotope N-15, improving reproduction in cattle by the use of Radioimmunoassay (RIA) to measure levels of progesterone in blood and milk of cows, and for control of animal diseases by the use of Enzyme Linked Immonosorbent Assay (ELISA).

Use of gamma radiation for food preservation, measurement of chemical residues in animal products, and use of bio-fertilizers, are possible areas of future applications.

AEA will continue to support implementation of projects in these areas through the Technical Cooperation Programme. The recipient institutes have the responsibility of the optimum utilization of the assistance provided, ensuring the sustainability of the activities, and transferring the benefits to the end users.

I wish to convey my appreciation to the Faculty of Agriculture of University of Ruhuna for agreeing to publish this special issue, which will help in disseminating the information on applications of nuclear technology in agriculture among potential users and decision makers.

Dr. M. Prinath Dias
Chairman,
Atomic Energy Authority of Sri Lanka