FAO/IAEA research and training in soil fertility at the IAEA's Seibersdorf Laboratories

Nuclear technology in soil and plant sciences is being developed and transferred through various mechanisms

by F. Zapata and G. Hardarson

The present century is experiencing an explosive increase in the world's population. It is estimated that by the year 2015 the population will be about 8 billion. As a consequence, there is a continuously rising demand for cultivated food, feed, fibre, and biofuel from effectively limited land resources. Several solutions have been suggested. In the developing countries, the most promising solution for the near future has become the intensification of agricultural production on currently cultivated land through either increased cropping intensity and/or higher yields.

The intensification of agriculture through the "green revolution" involved the development of new technologies and improved agronomic practices. These include the use of high-yielding cultivars, mechanization, irrigation, and especially agrochemicals. In intensive agricultural systems, crops remove substantial amounts of nutrients, which are replenished by the application of fertilizers. There has been, however, an increasing awareness over the last 10 years that the "green revolution" has made limited impact on the small-holder farmers in developing countries. Because of the lack of resources, and the increasing prices of commercial inputs, attention has been focusing on the analysis and subsequent improvement of low input cropping systems, and on a more efficient use of limited resources. Due to these factors, a systems approach concept to plant nutrition that integrates all sources of plant nutrients and crop production factors into a productive agriculture system to enhance soil fertility, crop productivity, and profitability has been recommended. This integrated plant nutrition system includes both the highest possible efficiency in the use of available chemical fertilizers and the maximum use of alternative sources of nutrients such as organic fertilizers, rock phosphates, and biological nitrogen fixation.

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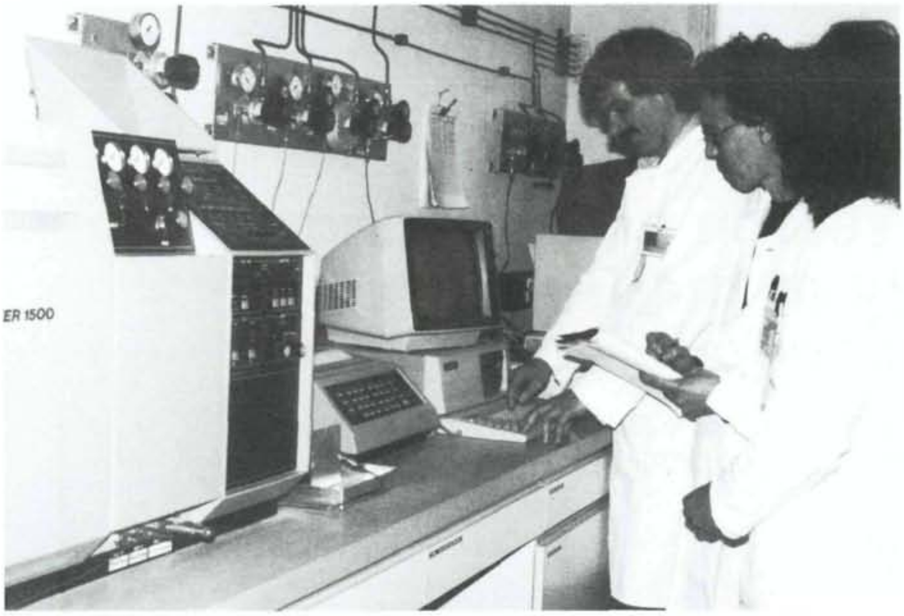
Nuclear techniques in soil science and plant productivity: Historical overview

Since its foundation in 1964, the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture in collaboration with the IAEA Agricultural Laboratory at Seibersdorf has promoted research, development, and transfer of nuclear technology to help countries establish better conditions for crop and livestock production. In the field of soil science and plant productivity, such research has been done through co-ordinated research programmes and technical co-operation projects conducted by the Soil Fertility, Irrigation, and Crop Production Section of the Joint FAO/IAEA Division. Isotopes are used as tracers, for instance to determine amounts and movement of nutrients, especially those derived from fertilizers in plants and soils. Radiation techniques using equipment such as neutron moisture meters and gamma density probes make it possible to follow the moisture and to measure bulk density changes in soil profiles in a reliable non-destructive way while saving time, effort, and money.

Isotopes and fertilizer use efficiency

It has been well established that crops respond to fertilizer application on most soils. Regular applications are essential for maintaining and enhancing soil fertility required for high productivity. About 50% increase in grain yield of cereals can be attributable to fertilizers. From 130 million tons consumed in 1984–85, nitrogen (N) accounted for 54%, phosphorus (P) for 26%, and potassium (K) for 20%. In 1985 the developing countries used 48 million tons of fertilizer worth approximately US $4950 million. This accounted for 38% of the total fertilizer consumption. The fertilizer consumption in developing countries had been increasing about 6% annually during 1980–85, whereas in the same period it only increased 1.8% in the developed countries. To meet world food needs, the use of N-P-K



Advanced instrumentation available at the Soil Science Unit — such as an automatic nitrogen analyser coupled to a stable isotope ratio analyser — permits an increased sample throughput for routine analytical services in support of the field projects of the Joint FAO/IAEA programme.

fertilizers must increase four to five times in the next 20 years. This projected increase in world fertilizer consumption is an indicator of the role fertilizers are likely to play in feeding an increasing world population.

Only a fraction of the fertilizer applied to the soil is taken up by the crop. The rest either remains in the soil or is lost through leaching, physical wash-off, fixation by the soil, and/or release to the atmosphere through chemical and microbiological processes. It is thus necessary to obtain information on the relative merits of different fertilization practices such as methods of fertilizer placement, times of application, and sources of fertilizers. This information would help to achieve maximum efficiency of fertilizer utilization in the most economical way and hence reduce costs of production.

The best combination of fertilizer practices (rate, placement, timing, and source) can be established for selected cropping systems by carrying out field experiments under different environmental (soil and climate) conditions. The classical methods used for this purpose are indirect because they are based on the measure of yield differences due to fertilization treatments. Experimentation using fertilizers labelled with stable and radioactive isotopes provides a direct and quick means of obtaining conclusive answers to the questions where, when, and in what forms fertilizers should be applied. ^{32}P- and ^{15}N- labelled fertilizers have been extensively used for such studies in several FAO/IAEA co-ordinated research programmes on rice, maize, and wheat during 20 years. The isotope technique involves applying labelled fertilizer to the crop and determining the percentage of nutrient element in the crop that was derived from the fertilizer. Fortunately, many isotopes are available and can be used as tracers in soil/plant relationships and related studies. The Soil Science Unit at the IAEA Seibersdorf Laboratories has played a key role in the implementation of these programmes by developing isotope techniques, providing analytical services, and transferring this technology to Member States through training. The adoption of these improved fertilizer practices in many countries around the world has resulted in savings of fertilizers worth many millions of dollars each year.

Isotope techniques also offer a quick and reliable means of obtaining information on the distribution of active roots, the location of zones where the density of absorbing roots is highest, and how these vary with seasons. Placement of fertilizer close to the zone of highest root activity and at a time when the roots are most active would therefore be of direct value for the formulation of rational fertilizer practices in tree crop plantations. A soil injection technique using ^{32}P-labelled phosphate solution was developed and used to determine the root distribution of various tree crops of economic importance to developing countries. The experimental details of injection and sampling techniques were worked out at the Seibersdorf Laboratories with the objective of reducing the experimental error. The Laboratories further supported the implementation of this programme by preparing and shipping thousands of ampoules filled with ^{32}P-labelled solution.

Radiation and management of water resources

In addition to mineral nutrient supply, water is one of the main limiting factors of agricultural production in many areas of the world. Therefore it is essential to develop adequate water management methods for better use of rainfall under dry farming conditions, or to improve the efficiency of water use on irrigated land. In this context, research with radiation techniques using equipment such as neutron moisture meters and gamma

Supportive research and fellowship training is carried out at the Soil Science Unit for a co-ordinated research programme on the management of nitrogen-fixing trees in restoring and maintaining soil fertility.

density probes has also been applied to develop improved water management practices in arid and semi-arid environments.

Water and fertilizer use efficiency studies under irrigated and rainfed agriculture in semi-arid regions were conducted to determine the management conditions under which crops best utilize costly inputs like manufactured fertilizers and irrigation water.

Techniques to study alternative nutrient sources

Inorganic fertilizers can be replaced to some extent with other sources of nutrients which are locally available or less expensive. Only certain plants, such as legumes and a few other families in symbiosis with appropriate microorganisms, are able to directly utilize atmospheric N_2. This process is called biological nitrogen fixation (BNF). The contribution of N to the nitrogen economy of both soils and plants through properly managed N_2 fixing systems appears to be the most promising alternative to supplement chemical fertilizer N in agro-ecosystems.

During the last decade, several FAO/IAEA research programmes have focused on measuring and enhancing the natural process of biological nitrogen fixation, especially symbiotic legume N_2 fixation in various systems. Furthermore, current programmes emphasize the improvement of both yield and nitrogen fixation in grain legumes through an integrated approach.

The measurement of the amount of N_2 fixed under field conditions is an essential requirement in any programme aimed at maximizing BNF. Of the many methods available, the ^{15}N isotopic techniques are the most reliable for providing quantitative and integrated values of nitrogen fixed in both natural and agricultural systems. It is the only method which permits one to distinguish the relative contribution of soil, fertilizer, and atmospheric nitrogen to the total plant nitrogen in the legume. This method has now become accepted worldwide as the most practical and useful tool for obtaining maximum benefits of BNF to crop growth.

The ^{15}N methodology for quantifying the amount of biologically fixed nitrogen by field-grown legumes was largely developed at the Agricultural Laboratory at Seibersdorf and has since been adapted to other N_2-fixing systems such as pastures and tree legumes, actinorhizal trees, and *Azolla*.

Similarly, rock phosphates are important potential sources of phosphorus in many countries. Direct application of finely ground rock phosphate, using local phosphate deposits, may be the cheapest source of phosphorus to crop growth on acid soils of the tropics. The Laboratory has also developed ^{32}P-radioisotope techniques for evaluating the phosphorous availability of local rock phosphates to plants. These techniques are routinely used by the FAO/IAEA programme for the agronomic evaluation of natural rock phosphate materials in connection with projects of the FAO Fertilizer Programme. Current research is focusing on measuring genotypic differences of nitrogen-fixing trees in phosphorus uptake from rock phosphates with the aim of maximizing nitrogen fixation and increasing soil fertility.

Support of IAEA's Seibersdorf Laboratory

The Soil Science Unit of the Agency's Seibersdorf Laboratories provides invaluable research and development support for the co-ordinated research programmes (CRP) and field technical co-operation projects co-ordinated by the soil fertility, irrigation, and crop production section of the Joint Division of the IAEA and

FAO/IAEA symposium in 1990 on the use of stable isotopes

In October 1990, the IAEA and FAO are jointly sponsoring a major scientific gathering — the international symposium on the use of stable isotopes in plant nutrition, soil fertility, and environmental studies. Early applications of stable isotopes were made in the geological sciences. Over the past few years, recent instrumental developments and innovative studies using various stable isotopes have led to widespread application in life sciences, agriculture, and environmental research.

This symposium is being organized to foster exchange of scientific information and main achievements in these important fields. It is anticipated that the participants will help to identify new research areas, potential applications, and means for developing and transferring such technologies with the ultimate goal of developing a sustainable and environmentally sound agriculture.

The symposium will be held in Vienna, Austria, from 1 to 5 October 1990. Further information may be obtained by writing to the Soil Fertility, Irrigation, and Crop Production Section of the Joint FAO/IAEA Division.

Food and Agriculture Organization (FAO). The Unit has played a key role in the development and transfer of nuclear technology in soil science and plant productivity since the inception of the Joint Division's programme in 1964.

Current back-up research. Ongoing research in the unit covers a wide range of topics, which generally can be grouped in two main areas:

- The first main research area is related to the restoration of soil fertility through biological nitrogen fixation as a means of improving plant productivity. Research activities in support of the CRP on the management of nitrogen fixing trees in restoring and maintaining soil fertility include genetic variation in nodulation and nitrogen fixation in tree species; selection of effective microorganisms (*Rhizobium/Frankia*) for tree species and inoculum technology; isotope methodological studies for measuring nitrogen fixation in trees; effects of environmental factors (soil and climatic) on nodulation and nitrogen fixation in tree species; effect of management practices on nitrogen fixation in tree species; selection of strains of *Rhizobium* for effective nitrogen fixation in tropical legume trees; and movement of strains of *Rhizobium* in the rhizosphere of legume trees.

Research in support of CRPs and technical co-operation programmes on biological nitrogen fixation by grain legumes is continuing. This research has mainly involved further development of the ^{15}N methodology to quantify biological nitrogen fixation under field and greenhouse conditions as well as ecological studies of rhizobia, the root-nodule producing bacteria, in the rhizosphere of grain legumes. The following list illustrates the type of work being conducted at the laboratory: quantification of N_2 fixation by various ^{15}N isotope approaches; effect of inoculation treatments on the movement of rhizobia in the rhizosphere, nodule formation and N_2 fixation of soybean, common bean, and tree legumes; time course of N_2 fixation of grain legumes; and effect of environmental stresses such as drought, salinity, and acidity on nitrogen fixation in grain legumes.

- The second main area of research is devoted to the improvement of the productivity of saline, acidic, and other deleterious soils. Research activities are carried out in support of two CRPs in this field: (1) use of nuclear techniques to improve crop production in salt-affected soils; and (2) increasing and stabilizing plant productivity in low phosphate and semi-arid and sub-humid soils of the tropics and sub-tropics.

Back-up research focuses on the identification of plant genotypes highly efficient in the utilization of resources under low input technology, as follows: initial screening and field testing of plant genotypes adaptable to certain deleterious soil conditions (saline or acidic, for example) or with high efficiency of water and nutrient uptake and use; and root biology and efficient use of soil resources (water and nutrients). Isotopic methods are being used to study the uptake (root parameters) and use of the resource in the plant (physiological parameters).

All these research projects are of great significance not only to sustainable agriculture but also in restoring and maintaining soil fertility for increased plant productivity.

Future research directions

Future programmes will continue to emphasize the use of nuclear techniques for developing a sustainable agriculture. In December 1988, a consultants' meeting discussed the application of techniques in molecular biology/modern biotechnology to the immediate and future programmes of the Agency's Soils Section. The consultants recommended work to be initiated in this field and indicated that the Section could make unique, highly important contributions in developing DNA probe work mainly in microbial ecology, as an effective extension of the existing vigorous programmes on management of nitrogen fixation by trees and grain legumes in the developing countries.

Similarly, the members of a review team of the Joint FAO/IAEA programme (28 November to 2 December 1988) recommended that increased emphasis should be given to the efficient use of water resources and methods of safeguarding and improving the quality of water resources. In many developing countries, food production is greatly limited by the inefficient use and/or improper management of water and by failure to adequately safeguard water quality. The off-the-farm impacts on fisheries and wildlife of water polluted by agriculture and by soil sediments are of grave concern.

Estuaries, lakes, and continental shelves are being rendered non-productive. This situation has serious economic and public health implications.

Training activities

Together with the back-up research, training is continuously provided by the Soil Science Unit at Seibersdorf in the form of training courses and fellowships in the applications of nuclear technology in soil science and plant productivity. This predominant role of training in soil science has a historical and scientific research and development basis in the laboratory.

- ***Training courses.*** Interregional training courses on the use of isotopes and radiation techniques on soil/plant relationship studies have been held yearly since 1978 at the Seibersdorf Laboratories. In addition, two specialized training courses on biological nitrogen fixation were conducted in 1985 and 1986. Each training course usually lasts 4 to 8 weeks and can be attended by about 20 participants. Advanced training on the use of stable and radioactive isotopes and radiation techniques is provided to scientists from developing countries actively engaged in several areas of soil science research, i.e soil fertility, plant nutrition, biological nitrogen fixation, and water use efficiency and irrigation management practices. A major new development was the 1988 Seibersdorf's training course focusing on root studies and how to study them using nuclear and related techniques.

The Soil Science Unit at Seibersdorf, with their available expertise and resources, is supporting regional and national training courses as well as other training events. It trains personnel of the other host centres, defines the syllabus of such training courses, provides lectures, and supplies training materials such as manuals, brochures, and video films.

- ***Fellowship training.*** The Soils Science Unit is also actively involved in fellowship training as an effective way of transferring its research and development to developing countries. Every year approximately 10 IAEA fellows involving approximately 55 man/months are trained for periods varying from 3 to 12 months.

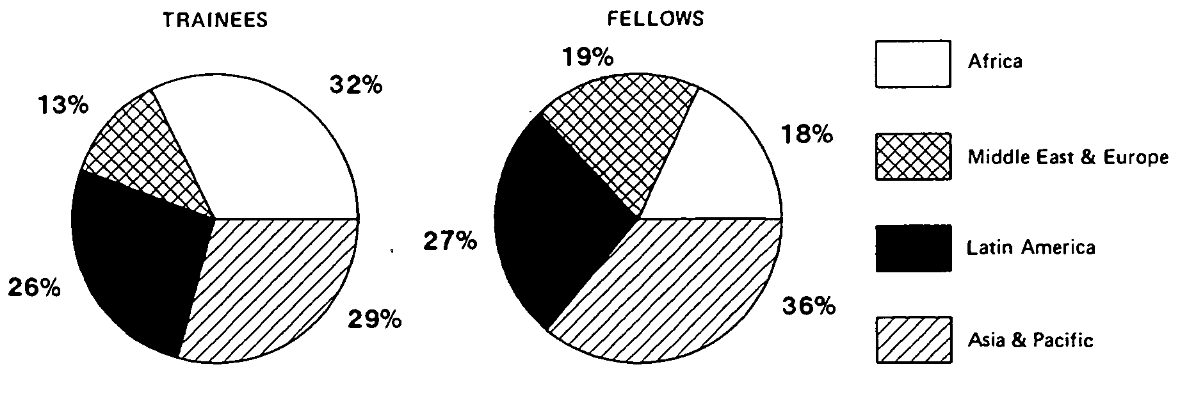
There are two categories of fellows: *Analytical fellows* are accepted for short-term periods of 2 to 4 months to learn isotope analytical techniques used in soil/plant research studies. This form of training

Training manual on the use of nuclear techniques in studies of soil/plant relationships

The IAEA is currently preparing a training manual covering all aspects of relevant nuclear techniques in soil fertility and plant nutrition research. This comprehensive coverage replaces and updates earlier manuals (1964, 1976) and incorporates the available expertise on the topics in the Joint FAO/IAEA Programme. Major headings and sections include:
- Stable and radioactive isotopes
- Methods for ^{15}N determination
- Isotope techniques in soil fertility and plant nutrition studies
- Use of ^{15}N methodology to assess biological nitrogen fixation
- Photosynthesis and crop productivity
- Use of neutron water and gamma density gauges in soil water studies.

The manual is intended to help young scientists from developing countries in the use of nuclear techniques in improving plant nutrition and therefore increasing food production in their countries. Further information may be obtained from the Soil Fertility, Irrigation, and Crop Production Section, Joint FAO/IAEA Division, or the Soil Science Unit at the IAEA's Laboratories, A-2444 Seibersdorf, Austria.

Training activities at the Seibersdorf Laboratories' Soil Science Unit



The Soil Science Unit at Seibersdorf has trained a total of 243 participants from 72 Member States in courses during 1978–88 and 90 scientific fellows during 1962–88 involving 635 man-months.

includes technical tutoring and hands-on practical sessions. Particular emphasis is given to specific techniques relevant to research conducted under technical co-operation projects, i.e. N-15 assay techniques by emission spectrometry. Whenever possible, group training of two to four such fellowship holders is arranged once or twice a year. *Research fellows* are accepted for periods between 6 and 12 months to work on a question within the unit's research programme. The fellows receive guidance on experimental strategies and use of isotope and related techniques relevant to a particular area of research which he or she will pursue upon return to his or her home country. The fellow is expected to complete and write up a piece of research work. This type of fellowship gives an opportunity for the fellow to work on the application of nuclear techniques to solving a particular research problem.

In addition, the Soil Science Unit receives IAEA sponsored scientific visitors, each spending 1 to 2 weeks in the IAEA Laboratory to get acquainted with recent developments on a particular topic of soil science research. There is also opportunity for fellow scientists to get on-the-job training as cost-free interns.

Supportive services

In support of the international/regional networks created by the co-ordinated research programmes of the Joint FAO/IAEA Division, the unit provides the needed analytical services of plant, soil, and water fertilizer samples for over 100 research contract holders participating in the various programmes. In this context approximately 15 000 isotopic and related analyses were performed last year. In addition ^{15}N-labelled fertilizer required for carrying out the experimental plans is weighed out and dispatched to participants in these CRP programmes.

The Unit also provides necessary analytical support to laboratories in developing Member States receiving IAEA technical assistance and lacking appropriate analytical facilities.

The Unit plays a leading role in the development of new isotopic measurement techniques/equipment and the refinement of those already in use for routine purposes. These developments are currently being used in IAEA technical assistance projects. For instance, the Unit has designed and assembled metallic vacuum lines for sample preparation for ^{15}N analysis by emission spectrometry. It supplies these to relevant technical co-operation projects in Member States.

Dissemination of scientific/technical information

The Soil Fertility, Irrigation, and Crop Production Section, with the support of the Soil Science Unit, has been very active in publishing the major scientific achievements from co-ordinated research programmes and results of practical importance from technical assistance projects.

The main findings of the Unit's back-up research carried out by the unit are also published in scientific journals. Some 10–15 scientific papers are published each year in reviewed journals.

The Unit also has a particular involvement in the preparation of training materials, such as training manuals and specialized video films.